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COURSE No. 6.21

INDUSTRIAL APPLICATIONS OF ELECTRICAL POWER

March 21, 1920 revised March 16, 1923. Prof. F.S.Dellenbaugh, Jr.

Scope:- A. Electric Motor Drive
B. Electric Heating
C. Electric Lighting.

The majority of the time covers the first item. Heating is discussed mainly in connection with industrial processes. Lighting is discussed from its bearing on production rather than from a photometrical standpoint.

Outline:- ELECTRIC MOTOR DRIVE

I. FIELDS OF APPLICATION.

1. Summary of some of the more important industries using electric power.
2. Types of Application dependent upon:
   - A. Speed Characteristics.
     - a. Constant Speed.
     - b. Variable Speed.
     - c. Reversing.
   - B. Torque Characteristics.
     - a. Starting Torque
     - b. Pull Up Torque
     - c. Maximum Torque
   - C. Load Characteristics.
     - a. Steady Loads.
     - b. Intermittent Loads.
     - c. Cyclic Loads.
   - D. Location and Protection of Motor.

II. SOURCES OF POWER.

1. Central Station.
   - A. Characteristics of Power Supply.
     - a. A.C. or D.C.
     - b. Voltages, Frequency and Phases, and Distribution.
     - c. Interference.
   - B. Charges or rates made by Central Stations.
     - a. Normal Systems.
     - b. Special systems adjusting for Power Factor, "Off Peak" loads, high Load Factor, Loads, etc.
2. Isolated Plant.
   - A. Characteristics of Power Supply.
     Same as II-1-A
   - B. Cost of power, or cost of operating isolated plant.

III. DELIVERY OF POWER FROM OUTLET TO MOTORS.

1. Methods of adaptation to Requirements.
   A. Motor Generator Sets
   B. Rotary Converters
   C. Rectifiers.
   D. Transformers.
2. Distribution within the Industrial Plant.
3. Safeguards and Standby Equipment.
   A. Storage Batteries
   B. Standby Steam Plants
   C. Main Line Fuse and Circuit Breaker Protection

IV. CHARACTERISTICS OF MOTORS.

1. A.C. or D.C.
2. Characteristics and Specifications.
   A. Types and Characteristic curves
   B. Voltage, Phases, Frequency.
   C. Temperature Rating, H.P. and Torques
   D. Speed:- Regulation and Adjustment.
   E. Control.
   F. Location, Protection, Enclosure, etc.

V. INFORMATION REQUIRED FOR APPLICATION OF MOTOR.

1. Load Conditions.
2. Power Conditions.
3. Location.
4. Control expected.
5. Unusual or Extreme demands.
6. The above should result in application giving:-
   A. Good Service.
   B. Long Life.
   C. Convenience, and Ease of Inspection or Repair.
   D. Flexibility.
   E. Economy.
   F. Continuity.
   G. Safety.
   H. Pleasing Appearance

VI. COUPLING TO LOAD

1. Direct.
2. Belts.
3. Chains.
4. Gears.
5. Miscellaneous

VII. AUXILIARY EQUIPMENT.

1. Switching.
2. Control.
   A. Hand Operated
   B. Automatic.
3. Protective Devices.
4. Measuring Devices.
   A. Indicating.
   B. Integrating.
   C. Recording.

VIII. TYPICAL INDUSTRIES AND APPLICATIONS.

1. Mining and Ore Handling.
   A. Hoists, Cranes and Elevators.
   B. Pumps and Blowers.
   C. Industrial Locomotives.
2. Steel Mills and Metal Working.
   A. Variable Speed and Reversing Motors.
   B. Fly Wheel drives.
   C. Automatic Control.
   D. Machine Tools.
3. Paper Mills, Tobacco Machinery, Woodworking.
   A. Constant Speed.
   B. Some Peculiar Conditions.
4. Dairies and Sugar Refining.
   A. High Speed Motors.
5. Printing and Rubber Machinery.
   A. Variable Speed.
   B. Extreme Ranges of speed.
   C. Semi Automatic Control.

ELECTRIC HEATING

I. AS PART OF INDUSTRIAL PROCESS.

1. Drying Ovens.
2. Japanning Ovens.
3. Embosser Heads, Linotype Pots.
4. Enamelling Ovens.
5. Annealing Furnaces.
6. Gun Shrinking Pits.

II. FOR HEATING ROOMS.

1. For commercial purposes, such as rising room in Bakery.
2. For comfort, or protection from freezing pipes, etc.

ELECTRIC LIGHTING

I. GENERAL LIGHTING OF BUILDINGS.
   1. Exterior.
   2. Interior.

II. SPECIAL LIGHTING FOR PROCESSES.
   1. High Intensity.
   2. Special Spectrum Value.
   3. Advertising Value.
   4. Special Optical Effects.

III. ECONOMICS OF LIGHTING.
   1. Increased Output.
   2. Safety.
   3. Relative expense of artificial vs. natural lighting.

H. Leather Goods.
- Gloves.
- Harness.
- Shoes.
- Shoe Repairs.
- Tanneries.
- Bag and Novelties.

I. Ceramics, etc.
- Brick Plants.
- Cement Mills.
- Glass Works.
- Tile Factories.
- Lime Kilns.
- Porcelain Works.

3. FRACTIONAL H.P. APPLICATIONS.

A. Household and Office Appliances.
B. Dental and Medical Apparatus.
C. Sign Flashers, etc.

4. FOOD PRODUCTS.

A. Bakeries.
B. Bottling and Capping Machines.
C. Candy Factories.
D. Cotton Seed Oil.
E. Creameries.
F. Dairies.
G. Flour Mills.
H. Spice Mills.
I. Sugar Mills.
J. Patent Foods.

5. GENERAL UTILITIES.

A. Broom Factories.
B. Building Construction.
C. Ice Machinery.
D. Laundries.
E. Refrigeration.
F. Trunk Factories.
G. Soap Factories.

6. TRANSPORTATION

A. Freight Handling.
B. Automobile Factories.
C. Railways and Railway Equipment.
D. Wagon Factories.
E. Elevators.
F. Dredges.
G. Ships.
H. Canals
I. Locomotives.

creased to 1,284 lamps by the end of the month it started. These were divided among 59 customers. About one year later the load had increased to 10,664 lamps distributed among 508 customers. Each lamp was rated 110 volt, 0.75 amp. 16 c.p. The power was generated in six dynamos direct connected to engines running at 350 R.P.M.

In 1884 the Alternating Current System was taken up by Westinghouse, and the first regularly operated A.C. generating station was started in 1886 at Greensburg, Pa. The Niagara Falls generators were put in in 1895 and the first all turbine Central Station was opened in Chicago in 1903.

The total generating capacity of the Central Stations in the United States in 192[illegible] was about 14,500,000 K.W.

II-1-A CHARACTERISTICS OF POWER SUPPLY.

A.C.-D.C. (a). The power supply may, of course, be either A.C. or D.C. Owing to the saving in transmission losses and expense due to the use of high voltage, and the ease of obtaining such high voltage with A.C., the latter has supplanted D.C. practically entirely for Central Station generation. There are a few D.C. distributing systems in some of the older cities, but they are gradually becoming extinct. It is interesting that there is a distinct tendency at present to prophesy the use of high voltage D.C. for transmission in the future, due to the large charging currents obtained with A.C. upon long lines. The high voltage D.C. removes many difficulties of transmission and with the development of rectifying devices can probably be obtained with good efficiency. The Thury system of constant current high voltage transmission has been tried out in Europe with some success but does not seem applicable to large powers.

Voltages. (b). The transmitting voltages have gradually increased. At the present time 220,000 volts is in use for long distance transmission and 110,000 volts is very common. For city distribution 22,000 volts has been common, but the tendency at present is towards 66,000 volt cables, with the probability of higher values in the not very far distant future. For use this is transformed to 110 volts for residence lighting and 220, 440 or 550 volts for factory power. For larger factory motor installations 2,300 volts is quite common.

Phases. Three phase power is almost universally used for long distance transmission. Residence lighting is furnished single phase of course, but is usually taken from a three phase generator, the different phases being connected to equivalent groups of lighting customers so that they remain practically balanced. In

connection with Rotary Converters six phase is used, bu this is obtained from the three phase by transformer connections.

Frequency:- The frequencies in this country are now practically standardized on 25 and 60 cycles, with the present general tendency toward concentration on 60 cycles. There are still many others in use, fortunately in limited areas.

15, 25,30,33-1/3, 40,50,60,66-2/3,125,133-1/3 and 140 cycles have all been used at various times, and still some others to a limited extent, as when alternators were first built they were rated as having a capacity of a definite number of lamps, for a small installation with no idea of coupling to a large system, so the designers made the frequency anything that might be convenient from construction standpoint. The standardization has proceeded very well, and this country is at present better standardized than many others.

In London in 1914 there were 41 separate generating stations representing 31 systems and 8 different frequencies.

In Paris 25 and 42 cycles are the leading ones, although in other parts of France there are many odd combinations.

In Italy 16,25,42,46, and 50 cycles are common, but with 42 cycles in the lead and 50 a close second.

Germany is fairly well standardized on 50 cycles.

DEVELOPMENT OF FREQUENCY IN THE UNITED STATES

1886 to 1893 — Period of belted generators. All single phase. Westinghouse 16,000 alternations per minute, (133-1/3 cycles). Thompson-Houston, 15,000 A.P.M. (125 cycles) Ft.Wayne Jenney Co., 17,000 A.P.M. (142 cycles).

High frequencies used largely because it made transformer design easy, generators were small high speed, and it was certain that it would not wink the lights.

1889 to 1890. — Development of Engine Type Alternators begun. Slow speeds require too many poles for high frequencies, so after study of situation 60 cycles introduced as good compromise

1892. — Niagara Falls generators operated by 250 R.P.M. water turbines. Seemed to demand still lower frequencies. 16-2/3 cycles proposed, partly owing to slow speed and partly as it was thought that commutating motors were to be used extensively and the crude designs then available would not commutate at higher frequencies than about 25 or 30. Westinghouse proposed 30 cycles as then lights

could be operated on circuit also, which would have been impossible with 16-2/3 cycles owing to flicker. Compromise of 25 cycles finally adopted.

1893. Worlds Columbian Exposition at Chicago lighted by 2000 KW two phase 60 cycle generators. Two phases obtained by two single phase machines displaced 90 electrical degrees, mounted on same shaft.

1898 to 1905 25 and 60 cycles rapidly becoming standard. An attempt was made to introduce 40 cycles as a compromise to meet all conditions, but was unsuccessful owing to the amount of apparatus already installed. Strong tendency noticed to swing to 25 cycles for power work, as converters and other machines worked better at lower frequencies.

1905 to 1920 60 cycle gaining supremacy over 25 cycles due to improvements in design of machines giving almost duplicate operating characteristics on either, and 60 cycles having several other advantages. Introduction of steam turbines extensively for power during this period.

II-1-A-c. INTERFERENCE.

One phase of power transmission that is receiving a good deal of attention at present is that of interference caused in telephone and telegraph lines by induction from the power lines. The telephone companies claim that as the source of the difficulty lies with the Central Station it is up to them to eliminate it. Unfortunately this is not possible without considerable expense involving special appliances and transpositions of the power system, the results being a reduction rather than a total elimination of the interference trouble. A long "Exposure" or parallel of power and telephone lines is necessary to obtain sufficient influence to cause trouble, and with the cable circuits met with in cities little trouble is encountered. The interference is of two kinds, a transient induction resulting in acoustic shock, and a steady hum reducing the intelligibility of the communications. The latter must be of frequencies in the more audible range, that is between about 200 and 2000 cycles per second, and so are caused by harmonics and not by the fundamental frequencies.

<u>The interference may result from:-</u>

Transient type giving Acoustic Shock.
Short circuits or grounds on the line.

Steady type, resulting from:
Harmonics in voltage wave of generator.
Harmonics due to Transformer magnetizing current.
Harmonics due to load characteristics.
High Frequencies from Arcing Grounds, etc.

II-1-B-a. CHARGES OR RATES.

Central station rates are very complicated for power service. The simplest type covers residence lighting where usually a rate of about 10¢ per KW Hr. is used. This was lately complicated by the addition of a coal clause to compensate for fluctuating fuel expense, and temporary increases of rate. For industrial power service it is customary to make a flat charge of a certain amount per month per KW installed, to cover the amount of station generating capacity that must be allocated to that customer to be ready to serve him at all times whether he uses the power or not. In addition, a charge of so much per KW Hr. is then levied on the power actually used. If the load involves high peaks a third charge is made involving an extra amount for the number of peaks over a certain value and of a fixed duration. The rates usually involve a rebate clause so that if more than a certain amount of power is used the charge is not as much as per KW.Hr.

II-1-B-b. SPECIAL RATES.

Unfortunately for the Central Station the generating capacity is not used at full load all the time. In fact load factors of 42% or less are usual with most of the companies. This means that the capital charges and overhead associated with the installed KW of generating equipment are much higher than they would be if the load were uniform all the time. Therefore various schemes to give this result have been tried or proposed. This is called the development of "Off Peak" load. The operation of ice machines in the summer with the excess power required to carry the heavier loads in the winter is one very successful extension of the Central Stations activities. Some method whereby different rates would be charged for power drawn at different times in the day would be very useful, but so far has not been extensively introduced due to the difficulty of obtaining proper meters.

Cost of low Power Factor.

The question of low power-factor upon Central Station lines is becoming quite serious. Before 1914 few of the stations were loaded to capacity and were anxious to obtain more business. During the years of the war and the difficulty in obtaining coal the customers of the Central Stations increased enormously. Their equipment and feeders then became fully loaded and the question of more capacity very important. In studying the situation it gradually began to dawn upon the engineers that they were furnishing along with the power, magnetizing current free. The situation

was similar to selling good and making free deliveries and packing of a very expensive nature. It also was unfair to the customers since it penalized those with high power-factor by making them carry the burden due to other customers with low power-factor.

It is true that low power-factor does not mean more input into the the generator from the prime mover, but it does mean enlarged electrical capacity for the same power output in the generators, feeders and transformers. The losses in electrical apparatus are almost all a function of current and not power. Therefore a Power-Factor of 50% means that the current is double that required for the same power at 100% Power-Factor, and that the electrical losses are four times what they would be at 100% Power-Factor, with all the electrical machinery correspondingly larger. This increases the expense of power generation due to increased capital charges, repairs, losses and overhead. The power-factors met with in the industries are surprisingly low, where some special means have not been used to improve them. 60% is not at all uncommon and during the parts of the day when the load is off peak, and in industries using a large number of small induction motors, Power Factors as low as 30% have been observed.

It is now generally conceded by the Central Station engineers that the extra cost of producing low power-factor current should be borne by those having low power-factor. That is the cost allocatedtto those responsible. There are several ways of doing this, but they all meet with the difficulty of ignorance on the part of the customer, and his antagonistic attitude to any changes in power rates the reasons for which he cannot understand.

Some central stations have cut the Gordian Knot by refusing to take customers on their lines who do not conform to a predetermined standard of power-factor. This usually provides a low limit of 80% for small customers, gradually being increased to 90% for large customers. This has not always met with favor for several reasons. The Central Stations being Public Utilities, the various Commissions have several times denied them the right of discriminating among customers. Also some customers would find it far more convenient to pay a penalty for low Power-Factor than to raise the Power-Factor of their whole plant, which is often very difficult or expensive. It is also commercially difficult to make the present customers with low power-factor improve it, and it would make a great deal of trouble if the power were arbitrarily cut off when they do not conform to the Power-Factor requirements.

Three methods, based upon sound engineering principles, of charging for low power-factor have been proposed;

1. Charge by Total K.V.A. Hours.
2. Charge an extra amount for Reactive KVA hours in addition to KW hour charge.
3. Charge with a penalty or bonus for power-factor greater or less than some predetermined point.

The first of these is objected to upon the grounds that it does not take into account directly the actual power used by the customer. Also an engineering investigation shows that it does not give as close an approximation to the correct allocation of charges as the other methods. It has the advantage of simple metering equipment.

The second method is the most accurate from an engineering standpoint, and is at present in common use in Europe. The only real objection is that it requires complicated metering equipment. A second meter must be added similar to the present watt-hour meters to record the Reactive K.V.A. hours which doubles the investment in metering and the expense of reading and recording the consumption. Two element meters have been developed in France which record the Watt-hours on one dial, the Reactive-K.V.A. hours on another dial, and the sum of any definite percentages of the two upon a third dial. This last dial gives the basis for the charge made, while the others record the power actually used.

The third method is the simplest to install, and is being used a good deal in this country. The power-factor tests are usually made periodically by a special inspector, largely to avoid the expense of installing power-factor meters in each case, and the charge upon the usual KW hour basis is multiplied by some predetermined power-factor, usually 80%, divided by the actual power-factor.

An approximate idea of the expense of low power-factor can be evolved from the central station records on file in the Public Utilities Commission report. The following figures are taken from the report of the Edison Electric Illuminating Company of Boston.

CHARGEABIL TO ELECTRIC END OF PLANT:-

1/2 Wages	0.123	¢/KW Hour
1/2 Tools	0.010	
1/2 Station Repairs	0.004	
Electric Repairs	0.057	
Distribution Expense	0.531	
3/4 Capital Charges	0.126	
3/4 Management	0.370	
TOTAL	[illegible]	

CHARGEABLE TO STEAM END OF PLANT:-

Coal	0.703	¢/KW Hour
Oil and Waste	0.002	
Water	0.009	
Balance of Charges under electrical end	0.302	
Taxes and other items chargeable to steam end	1.016	
TOTAL	3.588	

The portions chargeable to the electrical end may be assumed proportional to the K.V.A. Hours produced, upon a constant voltage system, and the rest of the cost is assumed proportional to the K.W. Hours. Upon this basis, assuming the costs for 1 K.W. Hour at a Power Rate of 1¢ per K.W. Hour, and various Power Factors, the following table may be calculated:-

P.F.	RKVA	Totl.KVA	¢/KWH	¢/KVAH	¢ Total	¢/RKVA
30%	3.17	3.33	0.746	.845	1.591	.218
40	2.28	2.50	0.746	.635	1.381	.167
50	1.75	2.00	0.746	.548	1.254	.147
60	1.33	1.66	0.746	.422	1.166	.126
70	1.00	1.43	0.746	.363	1.109	.109
80	.735	1.25	0.746	.317	1.063	.086
90	.470	1.11	0.746	.282	1.028	.059
100	.000	1.00	0.746	.254	1.000	.000
					Average	.114

The Column headings should be interpreted as follows:

R.F. is Power Factor.
RKVA is the Reactive KVA present for 1 KW at given Power-Factor.
Tot.KVA is the sum of the Reactive and Power Components, vectorially, given in KVA.
¢/KWH should be read: That part of the total expense of generating power which is proportional to the K.W. hours output, and so fixed in this case.
¢/KVAH should be read: That part of the total expense of generating power which is proportional to the K.V.A. Hour output, and so varies with the Power-Factor. Both of these last two are adjusted to give 1¢ at 100% Power-Factor.
¢ Total is the charge that should be made for 1 K.W. Hour at low Power Factors if the rate is 1¢ at 100% Power Factor.
¢/RKVA is the charge that should be made in addition to 1¢ per K.W. Hour for each Reactive K.V.A. Hour in order to compensate for the added expense of low power-factor. This fits in with the second method of charging for low power-factor mentioned above.

It will thus be seen that for very low Power-Factors the customers should be charged in some cases as much as 50% more than for power at high Power-Factors. The last column is also in percent, since it is based upon a 1¢ rate, and the average amount that should be charged for Reactive K.V.A. Hours, if this system is used, is 11.4% of the charge per K.W.Hour. This is lower than the rate usually used. In France 30% is used for this figure, and in this country from 20 to 25% seems to be thought a desirable value. Conditions in the production of power are so variable that it can only be approximated, but it is a more equitable distribution than making no charge for low power-factor at all.

As for an example, suppose that a plant used 1000 K.W. Hours at 60% Power-Factor and had a 1¢ Power Rate. Referring to the three methods of charging for a low Power-Factor, we get:-

Case 1.	K.V.A. Hours are 1000/.60 or 1670 @ 1¢ gives		$16.70
Case 2.	Reactive K.V.A. Hours at 802		
	25% of these at 1¢ gives	$2.00	
	1000 K.W. Hours @ 1¢ gives	10.00	12.00
Case 3.	1000 x 80/60 gives 1330 @ 1¢ gives		13.30

The charge for Case 1, is probably too large, as with this method the rate would be a little less than for the K.W. Hour method. The other two cases will be seen to give nearly the same results. The same power at 100% Power-Factor would, of course, be charged at $10.00.

Correction for Low Power-Factor

It usually will pay a customer to put in corrective apparatus where charges are made for low power factor. A large number of cases analysed show that the saving will pay for the corrective apparatus in two or three years time. In some cases the Central Stations are putting in the corrective apparatus under a guarantee that they will be payed for out of lower power bills, or even, in extreme cases, paying for them themselves by charging at past average power rates until the difference in power billed and power metered has paid for the installation.

Phase advancers and similar apparatus has been developed for raising the power-factor of induction machinery, but the only easily available motors with high power-factor at present are synchronous motors. These are not available for small power units, and sometimes cannot be used owing to low starting torques. The starting torques are gradually being much improved and small self-excited units have been proposed but are not on the market. Large installations can use synchronous motors direct, and adjust power-factor by field control. If part synchronous and part induction machinery is installed, the synchronous machinery can be run over-excited to compensate for the lagging current drawn by the induction machinery If only induction machinery is present, then separate corrective devices must be installed to raise the Power-Factor. These consists

of Synchronous or Static Condensers. The first type is the one in most common use and consists of a synchronous motor without load, used purely to draw a leading current and compensate for the lagging current required by other machinery, thus raising the Power-Factor of the installation. The Static Condensers have not been used a great deal. Paper condensers have been manufactured commercially and are chiefly useful in small units where the synchronous machinery is expensive in first cost and inefficient. Electrolytic Condensers are being developed, which offer some advantages owing to the small space required, and compete with Synchronous machines in small sizes up to about 500 KVA.

The three curves attached show graphically the amount of corrective apparatus necessary, and the added load that can be applied from its use. For instance, suppose that we have 1000 kilowatts installed operating at a Power-Factor of 60% and we wish to raise it to 80%. Then from the curve of CONDENSER K.V.A. REQUIRED we find that 60%, or 600 reactive K.V.A. is necessary. After installing this amount, the curve giving ADDITIONAL K.W. CAPACITY AVAILABLE shows that 26%, or 260 more KW at the original Power-Factor may be added to the lines, and still draw the same current. This will, of course, again lower the Power-Factor, and curve giving RESULTANT POWER FACTOR shows that the final Power Factor under these conditions will be a little over 75%, which is better than in the first case. It usually is not desirable to correct Power-Factor to more than 80%, as the amount of corrective apparatus for higher values becomes excessive and costly.

As an example of the Power Factors met with in practice, the following table shows some of the results obtained from an actual survey of an entirely normal and average industrial area in 1921.

Industry	Power Factor		
	Maximum	Minimum	Average
Pressed Steel	100	68	85
Chemical	88	79	84
Ship Building	88	35	68
Foundry	92	70	82
Textile, Large	78	28	67
Machine Shop	83	58	67
Metal Working	39	24	30
Textile, Small	49	24	40
Pattern Shops	79	8	25
Waste Manufacture	90	70	75

The first five represent large plants, the last five small plants.

II-2. ISOLATED PLANTS:

Isolated plants or privately owned generating stations were used extensively up to ten or fifteen years ago. Lately the increased expense and particularly the great difficulty in obtaining coal has reduced the number in use very greatly, the power users going over the Central Station Power. In general the Central Station gives better service at less cost than is possible with an isolated plant. Where D.C. is required or where exhaust steam is used as a part of the installation, such as heating and laundry work in hotels, boiling and drying in laundries and canning factories digesting the pump in paper mills, etc., there is some question as to which method of obtaining power is best, and no general rule can be given. Each case must be analyzed very carefully before a decision is made. The poor bookkeeping and lack of knowledge of the actual cost of isolated plants is often a source of the erroneous belief that the power is cheaper than purchased power from a Central Station, and in investigations of this sort care must be taken to be sure that the proper overhead, depreciation, repair and maintenance bills are added to the isolated plant costs. The owner of a small plant is very prone to charge merely fuel, oil, water and help to the power plant and imagine that he has covered all the expense.

Advantages of Central Station	Disadvantages of Central Station
No investment cost for generating apparatus	Except in large cities power is A.C. which must be converted if D.C. is required.
Service of large capacity system always ready, and probability of continuity very high.	If load is fluctuating, it may be expensive, as cost of peak loads high.
Cost of power usually compares favorably with isolated plants and often is cheaper in the long run.	Where steam is used in industrial process, or for heating, it must be generated anyway, and use of exhaust from engine operating generator makes private power cheap.
Can furnish power by transmission lines to plants located far from supply of coal or other fuel.	No control over voltage, other apparatus on same system may cause fluctuations.

The advantages and disadvantages of isolated plants are same as above, transposed. Central station power often seems more expensive because accounting system of industrial plant does not allow for all factors. Where electric power only is required and where a majority of constant speed A.C. motors can be used, there is little question but that the central station gives the best and cheapest service.

III-1. METHODS OF ADAPTATION OF POWER.

A. Motor Generator Set.
B. Rotary Converter.

Where direct current is required in large quantities, one of these must be used. In small sizes the difference in cost between the two is not great, as small rotaries are not made in large quantities, and do not give as satisfactory operation as the larger ones. Motor-Generator Sets on the other hand can be used for power factor correction and give easy voltage control. Therefore where the amount of power required is about 200 K.W. or less, Motor-Generator sets are used, in general. In larger sizes, Rotary Converters are cheaper and more efficient, and are therefore used unless flexible voltage control or power factor correction are very important.

Thus for plants requiring electro-chemical process, battery charging, or equalization of peaks in load by flywheel, motor generator sets of large size are always used, as the advantages offset the added cost and slightly lower efficiency.

C. Rectifiers.

There are several types:-

a. Synchronously driven commutators.
b. Mechanically vibrating contacts.
c. Electrolytic.
d. Mercury Vapor Arc.
e. Gaseous Conduction. Kenotron, "Tungar" or "S Tube"

Synchronously driven commutators have met with some success abroad but offer many disadvantages and difficulties. Mechanically vibrating contact types were developed for small sizes, but could not handle more than a few amperes, and were not rugged, being displaced by the gas type.

Electrolytic rectifiers find a large field for lightning arresters and electrolytic condensers, but are not used commercially as power rectifiers. Mercury Vapor rectifiers are manufactured extensively under Peter Cooper Hewitt patents, and are used for small battery charging plants in many cases. They are built in standard sizes to deliver up to about 50 or 60 amperes, and have been experimented with in much larger sizes for producing D.C. for Railway work, but so far have not been commercialized in this field.

Ionized gas rectifiers are only made in small sizes for automobile lighting batteries and similar demands, capacity up to about ten amperes.

D. Transformers.

These must practically always be used where A.C. power is transmitted, whether other apparatus is used also or not. Their characteristics are so well known that little need be said. Auto transformers are used in some cases on account of cheapness, but do not give as satisfactory service, except for starting duty, etc. As high as 99% efficiency is obtained in large units.

III-2. DISTRIBUTION WITHIN THE INDUSTRIAL PLANT.

The power supply is derived from the Central Station outlet or the isolated plant switchboard. It must then be wired around the buildings to serve the various motors. The question of proper wiring is a detailed study in itself and the Fire Underwriters require approval of the finished installation by an inspector. For this reason the wiring must be done by a licensed electrician. A special code is available, prepared by the Board of National Fire Underwriters, giving information upon the proper size of wire, carrying capacity, etc. In general the wire is run through iron pipe conduit with special fittings for bends, terminals, etc., Care must be taken to see that the iron conduit is not included in an A.C. magnetic circuit, as it will cause high reactance drop, and power loss. This can be avoided by always having the outgoing circuit and its return wire in the same conduit. This may seem a foolish warning, but the mistake of separating the different phases of a three phase conduit job in separate pipes is still made every now and then.

III-3. SAFEGUARDS AND STANDBY EQUIPMENT.

A. Storage Batteries.

The expense of storage batteries usually prohibits their use except where conditions warrant it. Their chief value commercially is for standby power, and emergency lighting. In plants run on A.C. a charging device must be installed, and batteries would only be used for lighting in case of shut down as naturally they would not operate A.C. Motors. They are used extensively by central stations and railroads, to insure continuous operation of power supply.

B. Standby Steam Plants are usually installed by Central Stations relying on water power for their energy, where the water may run low at certain periods of the year. In some cases old isolated plants are retained after the factory has been cut over to Central Station supply, but usually it is not economical to do so since the continuity of Central Station Service is very excellent.

C. Circuit Breaker and Fuse protection should always be furnished as near the source of power as possible within the factory, to protect the wiring and reduce fire risk. This should consist of approved appliances properly mounted and if not on a special switchboard, they should be enclosed in fire proof boxes, and kept locked.

The question of calculating the right size is usually settled by the carrying capacity of the feeders leading out from the point where the protection is installed. However, in a plant with a lot of individual motor drives, the diversity factor of the load cycles of the various machines may result in small wiring being sufficient, while occasionally a high peak may be developed for a short interval of time. In this case the size of the protective devices must be calculated from the probable peak loads, which is often a rather intricate proposition. It is also a good plan to use inverse time element breakers, which will allow a small overload to exist for a predetermined amount of time before opening, but will cut off a heavy short very quickly.

IV. CHARACTERISTICS OF MOTORS.

D.C. A. Types and Characteristics.

WINDINGS:-

<u>Series</u> - High Starting Torque. Poor speed regulation. Characteristics very good for certain applications such as traction, hoists, etc. Will run away if disconnected from load.

<u>Series-Shunt</u> - Similar to series, modified by small shunt field to prevent runaway and improve speed regulations.

<u>Compound</u> - Compromise between high starting torque and close speed regulation. Admirable for a large part of industrial applications as they give reasonably close speeds, can be adjusted by field weakening, and give good starting characteristics for heavy duty.

<u>Shunt</u> - Very close speed regulation. Cannot be called upon for high starting torques with ordinary design Give wide range of speed control by field weakening.

<u>Differential</u> - Series winding opposed to shunt giving flat speed regulation or increasing speed with load. Generally unstable and very seldom used.

COMMUTATION:- <u>Non-Commutating Pole.</u>

Oldest type. Tendency to spark at extreme loads. Will not give more than 100% increase in speed by field weakening and in many types 50% increase is limit. Sparks badly above these limits. On load of very peaked nature size of motor often determined by sparking rather than by heating and so materially worked uneconomically. Satisfactory on series or heavily compounded motors.

Commutating Pole.

Originated by Electro-Dynamic Co. under Pfatischer patents. Commutation very good under even extreme overloads. Heating chief criterion of motor size, in most cases. Not required on series motors, but sometimes used. Generally carries light compound field even on "Shunt" motors to stabilize speed at weak fields, since commutating pole then tends to neutralize main pole and causes hunting and even bucking. Not used in sizes below 1 to 2 H.P.

Compensated. A compensating winding is one wound in slots in the pole faces to oppose and neutralize the effect of armature reaction. As it is expensive and makes motor bulky it is only used for special service, such as extremes of speed change by field weakening, or extreme peak loads. It may be used with or without commutating poles, but as commutating pole windings can be made very small when compensating winding is used, and give better commutation, they are generally used. Cost of motor is always considerably above usual type.

B. Voltage. Has already been discussed. 110 volts for 1 H.P. or less, 230 for majority of applications, and 550 or 600 where power has to be transmitted any distance or size of motors is large (about 75 H.P. or larger) is common practice. Considerable overlapping of these ranges will be found where other causes make it practicable. As high as 3000 volts has been used in railway applications.

C. Rating H.P. There are several ways of rating the H.P.; the commonest is constant duty rating, formerly at 45° C. temperature rise in hottest part, and now 50°C. in many cases. The usual ratings employed are:

Constant duty, 25% overload, 2 hrs. 45°.
Constant duty, 50% overload, intermittent 50°.
Maximum duty.
Double rating for variable speed.
Intermittent Duty.
Vehicle and Traction Rating.

Where load is of intermittent nature the "root mean square" current must be determined to fix size of motor. This requires special analysis of load cycle conditions. Thermal ammeters are now being used for this purpose to good effect although recording instruments give better indication of conditions to be met.

D. Speed.- Regulation and Adjustment.

The speed may be varied by changing either the voltage or the flux.

Speed Control by voltage.

May change voltage of line, or have several lines of different voltages that are used in various combinations. Obsolete.

Series resistance in armature circuit reduces voltage by IR drop. This is standard method for starting and in some cases for obtaining slow speed, but is inefficient and should not be resorted to where low speed required for prolonged periods.

Speed control by flux variation.

Commonest method is field weakening by field rheostat. Can obtain as high as 4:1 speed range with properly designed motor.

Special types of motors, used chiefly for machine tool work, retain constant field current and vary reluctance by changing air gap. Lincoln motor moves pole cores in and out by gear and threaded spindle. Reliance moves armature axially in or out of field.

E. Control. May be: - Hand operated.
Remote.
Semi Automatic
Automatic

It is obtained by a combination of switches, relays, and contacts, operated by various means and involving one or more of the methods of speed adjustment discussed. This will be taken up in further detail under control section.

F. Location. Motors should be placed so that they are accessible for oiling and inspection. Routine inspection should be always used. They should not be installed adjacent to hot steam pipes, furnaces, etc., and means for ample ventilation provided. An open motor enclosed in a tight box is not much better off from the standpoint of cooling than a fully enclosed motor, and may b worse, due to poorer conductivity of enclosing medium offsetting its larger area. They must also be installed in position that is as far as possible out of the way and at the same time convenient for driving the machine, and for inspection.

Usually an enclosed motor is larger and more expensive than an open motor of the same rating. Enclosing covers should be used wherever there is dust or dirt likely to cause trouble with commutation. Sometimes covers over upper half only are sufficient. There are several types of enclosures:

Semi-enclosed.
Enclosed, forced ventilation.
Fully enclosed.
Splash proof.
Moisture proof.
Gas Proof.
Explosion proof.
Submersible.

IV. A.C. Motors.

A. Types:- Induction. Squirrell Cage. Gives starting torque about equal or slightly greater than full load torque and pull out torque of about twice full load torque. Speed regulation or slip 5 to 10% no load to full load, depending on design. Special high resistance end rings sometimes used to increase starting torque, but at sacrifice of efficiency and speed regulation. Two or three phase motors self starting. Single phase requires special split phase starting winding. Used in sizes from about 1/4 H.P. to 50 H.P. and occasionally larger. Repulsion starting, induction running single phase motors are more expensive than split phase, but give higher torque.

Wound rotor. Only made for polyphase circuits. Used for high torque starting, and for speed control. Starting torque equal to pull out torque may be obtained, and 2:1 speed control, but efficiency decreases with the speed. Customary practice uses this type in sizes from about 10 to 1500 H.P. Practically always used in larger sizes due to difficulty of starting with reasonable current and torque for other type.

Synchronous. Inherently constant speed. Very seldom used on single phase circuits. Self starting in some cases as induction motor, the eddy currents in pole faces or amortisseur windings replacing a squirrel cage winding. Starting torque about 1/3 full load torque present maximum. Sometimes starting motors of induction type attached. Used chiefly on loads of the nature of pumps and blowers, or for operating motor generator sets, where constant speed is desirable, low starting torque not a serious detriment, and load is not applied until after motor up to speed. One great advantage is power factor correction. Not used in small sizes. Customary range about 500 to 2000 H.P.

Commutating Motors. Used a great deal in small sizes for repulsion start induction motors. This type gives series motor characteristics for starting, and squirrel cage induction motor characteristics for running. Majority are used in sizes from 1/2 to 10 H.P. but 1/10 to 25 H.P. are manufactured.

Other types of commutating A.C. motors not so common. There are various combinations, designed chiefly for speed control and power factor correction, but they introduce complications and expense that seems to have prevented the industries from adopting them.

In very small sizes, 1/4 H.P. down to a few watts output series motors are used.

B. Voltage, Phases and Frequency. This is fully discussed later on.

C. Rating H.P. and Torques. The determining factor in applying A.C. motors is usually the torques to be developed rather than H.P. The two are, of course, inter-related, but for a known H.P. required, the starting and intermittent peak torques may be high enough to make a motor having the correct average, a very unsatisfactory application. The torque must, therefore, always be very carefully investigated. The H.P. Ratings of A.C. motors are almost always constant duty ratings for 45 or 50° temperature rise, although in some cases with motors subjected to occasional extreme conditions or loads of cyclic nature with wide variations, maximum duty and intermittent ratings are used.

D. Speed, Regulation and Adjustment. Induction motors give 5 to 10% speed regulation under normal conditions. Very large sizes regulate even closer. Synchronous motors of course operate always at synchronous speed.

Adjustable speed can be obtained by wound rotor induction motors at the expense of efficiency. Where the installation warrants it, exciting current of low efficiency can be supplied by special means to rotor and improve characteristics of operation. Some times this is also done by adding a commutator and using special connections. Cascade on concatinated connections of two wound rotor motors is sometimes used for speed control, and occasionally the frequency of the generating set may be varied, but is very unusual practice, and can only be used where all the connected load is to have speed variation of the same amount.

Special motors for variable and adjustable speed have been developed, but are not used extensively due to cost and complication.

E. Control. The control of A.C. motors, up to their inherent limitations, is just as flexible as for D.C. machines. As above it may be:

- Hand operated.
- Remote.
- Semi-Automatic
- Automatic.

F. Location, enclosure, etc. The same factors apply here that were discussed under D.C. motors. In this regard Squirrel Cage induction motors have some advantages, as there is no danger of explosion, since no sparks are produced at the motor. There also is no commutator and its required care and protection on the majority of industrial A.C. motors. Therefore in general A.C. motors will operate satisfactorily under worse conditions as regards dust, gases, moisture, etc., and with less enclosure or protection, than D.C. motors.

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MISCELLANEOUS:

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History and Development. See articles in January issues of Electric Journal and G.E. Review for 1914 to date.

V. MOTOR APPLICATION DATA

Name of Factory _______________________________

Address _______________________________

Name of Engineer and other persons interested ______________

Capitalization, credit Rating, Value of Product ______________

Sources of Power: Isolated Plant, Give Capacity, No. of Generators, and Name Plate Data. ______________________

Central Station. Give Name of Station ______________

Voltage of System ______________

Frequency and No. of Phases ___________

Characteristics of Power:

Voltage _ _ _ _Frequency _ _ _ _ Phases _ _ _ _ _ _ _ _ _
Normal variation of voltage _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
Maximum reduction of voltage when starting motors _ _ _ _
Maximum over voltage for any reason _ _ _ _ _ _ _ _ _ _ _ _
Normal variations and max. and min.variation of frequency _
What is used to convert power for factory use? _ _ _ _

Characteristics of Driven Load:

Type of machine to be driven _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
Speeds required _
Motor: Direct Connected,-Belted,-Geared,-Chain Drive
_ _
Size of driven pulley, gear or sprocket _ _ _ _ _ _ _ _ _
Maximum size of pulley gear or sprocket possible _ _ _ _ _
H.P. required at each speed, per manufacturer _ _ _ _ _ _
By test _
Estimated _
Give sketch of load cycle with max. and min.load peaks _
Position of Motor with respect to driven machine. Give sketch if necessary. State clearances on all sides of motors if it is to fit inside machine frame. Attach drawings if motor is to attach directly to preparedbase on machine.

Desired Control: Hand Operated,-Remote Hand Operated,-Semi-Automatic Full Automatic.
Duration of motor operation on each control point _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _.
Sketch rough wiring of control to motor, showing push button stations if they are to be used.

Protection:- What protection is to be provided for this motor? _
_ _

General Factory Conditions:
Fire Risk: Inflammable Liquids, Gasses or Dust?
Danger to Motor: Abrasive or corosive Liquids, Gases or Dust?
Ventilation conditions: Good air circulation _ _ _ _
Poor air circulation _ _ _ _
Normal, Max.&Min. Air Temperature _ _ _ _ _ _ _
Moisture present _ _ _ _ _

Auxiliary Motor Equipment:

Standard Starter and Rheostats: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
Open, or with enclosing covers of type: _ _ _ _ _ _ _ _ _ _ _
Floor, Side Wall, or Ceiling Mounting _ _?_ _ _ _ _ _ _ _ _ _
Horizontal or Vertical? _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
Standard pulley, shaft & rails? _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

General: Will motor be accessible? _ _ _ _ Will it get routine inspection? _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
Will it be subject to wilful or playful tampering?
_ _
What motors, if any, are used on similar machines?
_ _

V. Motor Drive.

A. Requisites.

a. Adaptability. Motor chosen must be adapted to suit the application. Thus a machine requiring variable speed with a few high peaks of speed can be well handled by all field control on a D.C. motor, while a similar application having largely a high speed with a few momentary low speed requirements will give better service if a motor of high normal speed is used, with a small adjustment by field control, and the low points obtained by armature control. In each case several motors will be found, all of which will operate the device, but one of which will be the best and most adaptable to the particular drive.

b. Flexibility. This is linked up with the above, but is broader in that it implies ease of handling and other features as well. If it is a machine tool application for instance, greater flexibility will be obtained if the motor is self contained in the tool, as the arrangement of tools can then be made to route the work in best manner. Possibility of future changes, installation of automatic control, and many other local factors varying with each case must be considered to obtain the maximum flexibility.

c. Economy. The cost involves several factors:-

a Interest on investment.
b. Cost of power.
c. Depreciation.
 I. Amortization.
 II. Maintenance and Repair.
d. Value of increased production.

A balance between all the cost items must be obtained before it is certain that the most economical arrangement has been obtained. As a saving due to motor efficiency, for instance, is recovered year by year, it must be capitalized in terms of first cost. This is a problem in compound interest, and may look involved, but can be determined, comparatively, by the following simple method:

The yearly cost of operation is equal to the cost of power plus interest on the investment, plus depreciation.

Let: W = KW Output.
H = Hours per year operated.
C = Cost of power in dollars per KW hour.
I = Investment or price of one proposed motor.
J = " " " " another proposed motor.
i = per cent interest
d = Per cent depreciation.
E = Efficiency of Motor I.
e = " " " J.

Then total annual cost = $WHC/E + Ii + Id$ and $WHC/e + Ji + Jd$

The economy of the two choices will be identical if these two costs are equal:

$$WH/E + Ii + Id = WHC/e + Ji + Jd$$

From which: $(I - J) = \left[WHC/(i+d)\right] \left[(1/e - 1/E)\right]$

Therefore, $(I - J)$ represents the capitalized value in first cost of the increase of efficiency. That is, the amount more that can be paid for a more efficient machine and still have the same total cost. Obviously a more efficient motor costing less than this amount more than a cheaper but less efficient one will be economical to buy.

This does not take into account the question of increased production, which is a credit to the motor side in most cases, and depends more upon the drive application than upon the motor efficiency.

d. <u>Continuity</u>. A fixed charge is always placed upon each machine in a shop or factory, which continues whether the machine is producing or idle. Therefore continuity of service is important for economy as well as for its bearing on production. The installation giving the least chance for breakdown, and the easiest replacement will be the most advantageous. This may mean individual drive for each machine, or possibly group drive, using duplicate motors. If an isolated plant is intended for operation of the factory, it should be arranged so that breakdown service can be obtained from some central system, unless there is some particularly imperative reason for choosing power of different characteristics.

e. Safety. Protection for the motors, equipment, and personnel is very important. This involves careful analysis of fuses and circuit breakers for the motors, method of coupling and maximum torques to be certain driven machines may not be broken or strained in case of jamming, guards over gears, live wires,etc. to protect operators, and proper enclosure or covering of motors where inflammable dust or gases may be present. The commutator must also be protected from dust and dirt that is likely to clog the brushes or interfere with commutation.

f. Appearance. A pleasing appearance will usually promote greater care on the part of the workmen. It is also usually indicative of a more clearly thought out plan of installation, and like the form of the "Follow through" in golf or tennis, has not a direct influence upon the work performed, but indicates that it has been done better.

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Chapter II.

V-2. Choice of System. AC versus DC.

In general D.C. is preferable where wide ranges of speed and particularly flexible control is necessary. Wherever inherent characteristics of load do not demand D.C., alternating current is used since it is more easily available, can be transmitted with less loss over distances almost prohibitive to D.C., and can be obtained from Central Stations.

In some cases the choice of power may be determined by the type of work to be performed. While it may not be in the nature of a motor load, it may be the determining factor that will decide upon the system used. Thus in garages D.C. is necessary for battery charging; in Electrolytic refining and similar plants, such as production of Sodium, Aluminum, etc. D.C. must be used; plants handling steel may have many magnetic clutches upon machine tools, or lifting magnets, requiring D.C. Electric welding may use either D.C. or A.C. depending upon the method and may be a determining factor.

- DIRECT CURRENT -

Advantages:	Disadvantages:
Easy speed control through wide range.	Expensive to transmit.
Can combine with storage batteries for stand-by or for smoothing generator load.	Voltage not flexible.
Large starting torque easily obtained.	Commutators introduce chance for trouble (very small) and fire risk.
No troubles from low power factor.	If used in isolated plant cannot tie to Central Station for breakdown service without additional apparatus.
Power requirements of tools a little easier to read.	
May be required by some processes.	

- ALTERNATING CURRENT -

Advantages:	Disadvantages:
Easily and economically transmitted.	Variable speed difficult and complicated.
Voltage easily transformed.	Large starting torques difficult to obtain.
Some types of motors have no open of sliding contacts and thus are safe in inflammable dust, etc.	Low power factor easy to get and expensive.
No commutators on usual types eliminates chance for trouble.	
Power can be obtained from Central Stations.	

DIRECT CURRENT:- If D.C. is used there is a choice as to voltage. For some time a four wire system was used to obtain variable speed, the voltage between the wires being unequal, such as

40-80-120. By combinations of different pairs of wires six values of voltage can be obtained from 40 to 240 volts. The improvement in speed adjustment by field weakening has made this obsolete. 230 volts is now the standard for all average installations, three wire if lights are carried on same mains, and two wire if for power only. Motors of less than 1 H.P. are usually run on 115 volts, while in large installations and for railway work 500 or 600 volts is used. This higher voltage is considered dangerous for ordinary installations, but has to be used where much power is required in order to decrease the amount of copper required for transmission. Higher voltages than this have been obtained from railway work, but are not used in Industrial Plants.

ALTERNATING CURRENT:- There is a wide choice of characteristics with A.C.; Voltage, Frequency, Phases.

Voltage:- 220 volts is the average standard for moderate industrial plants. This combines low line loss for short distances with great safety and ease of insulation. But owing to ease of transformation, various voltages may be used in one plant if desirable, and the following list gives about the range of voltages usually met with:

0-5 H.P.	110 volts.
0-75	220
7-1/2-200	440 and 550
20-1500	2200
50-2000	3800 to 4000
2000 up	6800
1000 up	11,000 (synchronous motors only).

Comparison 60 and 25 Cycles

60 Cycle	25 Cycle
Better speed range.	Limited Speed Range
3600, 1800, 1200, 900, 720, R.P.M. etc.	1500,750,500 R.P.M. etc.
Better for illumination	Maximum Torque greater
Poor on very low speeds due to large magnetizing current.	Good for very low speeds.
More flexibility in design.	Larger air gap allowable.

PHASES:- Except for lighting and small power units, single phase is now out of the question. It usually is used for sizes below 3/4 H.P. and may be used as large as 10 to 20 H.P. where no other form available.

This leaves two and three phase for a choice. There is very little difference in the operating characteristics of motors for either one. Three phase will give about 5% greater capacity for the same material, and slightly greater torque and power factor in some cases. Two phase is chiefly advantageous for lighting networks in cities, and three phase for long distance transmission as it requires less copper for the same loss.

TWO PHASE	THREE PHASE
Balancing of a single phase load easier	Only three lines instead of four.
Only two transformers required.	Can use Delta or Y connection giving voltage ratio 1.73 : 1.
71 and 50% voltage easily obtainable for starting	Can burn out one phase and still run.
Good for networks in cities, with mixed load.	Slightly more capacity in motors and transformers for same amount of material.
Four wires usually required.	Spare transformers smaller,- 1/3 of total capacity instead of 1/2.
	Better for long distance transmission as only three wires required.

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V-5. MOTOR RATING REQUIRED FOR CYCLIC LOADS.

If the load is constant it is easy enough to pick out the proper motor size. If the load is jumping around, however, it is not evident at once how large a motor is required. If this load is cyclic, that is repeats itself again and again, then definite analysis can be made. Thus on a screw machine with say five cuts to complete the screw, there will be five different requirements of power and speed with probably a sixth to run down the stock for the next screw. These requirements will repeat for every screw, the time for the whole cycle being the time to make one screw, which will be in the neighborhood of from a fraction of a minute to a few minutes depending upon the work being done.

Due to the mass of a motor it obviously takes an appreciabl time for the temperature to rise under any given load. The time to rise to constant temperature varies from about an hour for small motors to several hours for large machines. The main limiting feature of a motor application is the temperature rise, since it is heat which destroys the insulation and results in ultimate motor failure. Sparking at the commutator of D.C. machines used to be criterion, but with the introduction of commutating poles loads up to five times normal can be carried without sparking. Therefore, temperature rise is the important factor. The maximum temperature should be maintained less than 100°C, which has been found safe for modern insulation and gives a motor life of at least ten years. Unfortunately it is inconvenient to measure temperature directly and so the rating is given in terms of the H.P. which will result in a certain temperature rise, usually taken as 45 or 50°C.

With cyclic loads of short duration a peak may exist for such a short time that it has little effect upon the temperature. Therefore, it is not necessary to use a motor of rating equal to maximum load. On the other hand if the peak is of long duration compared to the rate of temperature rise in the motor, then the maximum rating is necessary. Suppose we have a load cycle as follows:

Time	H.P.
10	5
10	25
10	10
10	5
10	0

After the five steps it is considered that it then repeats the same thing. If the time units are seconds, then it is evident that motor will not have time to heat up on peak. If each time of 10 is considered to be an hour, then motor will heat up. The

temperature rise is proportional to the losses. The losses are partly constant and partly proportional to the square of the current. On overloads the variable losses are greater than the fixed losses and so it is approximately correct to assume that the losses and hence temperature are proportional to the square of the current and hence the square of the H.P. with constant voltage.

Thus as an approximation of the power required upon cyclic loads we can take the root mean square value of the load cycle, provided that none of the parts have long duration compared to the rate of rise of motor temperature.

The above load cycle will then give a root mean square H.P. of about 12.5 for a total time duration of 50 seconds. If the total time were 50 minutes then the overload would only be on for 10 minutes and it is probable that the 12.5 H.P. motor would still be satisfactory. If the total time were 5 hours then the temperature would have time to rise during the 25 H.P. peak and a 25 H.P. motor would have to be used. If the time were intermediate between 1 Hour and 5 Hours a motor rating intermediate between 12.5 and 25 H.P. would be required.

If the time of each part of the cycle is different this must be taken into account and the mean square value is taken from the values of $(H.P.)^2$ seconds (or minutes). Also if the speed varies the ventilation will vary and this will change the rate of temperature rise and must be taken into account. A better knowledge of the motor is required to take into account the ventilation, but roughly it can be assumed that a 100% change in speed will have a 50% effect on ventilation. That is if the speed is doubled 50% more H.P. can be carried with the same temperature rise.

Time	H.P.	Speed	$(H.P.)^2$ Sec.	Equ. Heating H.P.	Equ $(H.P.)^2$ Secs
1	10	150%	100	10/12.5 = 0.8 x 10=8	64
2	30	50%	1800	30/24 = 1.25 x 30=37.5	2820
5	5	200%	125	5/7.5 = 0.665x5=3.32	55
3	15	100%	875	15/15 = 100 x 15 = 15	675
2	0	0	0		0
13			2690		3614

$2690/13 = 207$ and $\sqrt{207} = 14.4$ H.P. (Case #1)
$3614/13 = 278$ and $\sqrt{278} = 16.7$ H.P. (Case #2)

Case #1 the root mean square H.P. was figured without taking into account the speed. The time units may be anything provided the duration of any one part of cycle is short compared to rate of temperature rise. The speed is taken inversely as the H.P. similar to the speeds that would be obtained with a series motor.

The Equivalent Heating H.P. is then figured on the basis of 100% chan in speed giving 50% change in allowable H.P. for same temperature. Thus during the 10 H.P. period the motor is running at 150% speed and so could carry 12.5 H.P. with the same temperature rise that would be obtained with 10 H.P. at 100% speed. The equivalent heating H.P. is thus less than 10 in this ratio. The root mean square value thus taking into account the speed is given in Case #2 and is a little higher than it was when disregarding the speed. If the motor had been a shunt motor with field control to get speed changes it is probable that the higher horsepowers would have been attended by higher speeds and in this case the R.M.S. H.P. allowing for speed variations would have been less than that given in Case #1.

Where very accurate information is necessary it is possible to calculate the exact temperature rise of the motor, with a probable accuracy of within 1°C. A mathematical expression for the temperatur rise of the motor is necessary. This can be obtained easily by analogy. In a circuit containing Inductance. Resistance and a battery, when the circuit is closed the current rises logarithmically until the state of steady flow is reached. In a motor we have a source of energy in the losses that produce the heating. The ventilating and dissipative constants of the machine transfer this heat to the air. But if the machine starts cold the mass of the machine must be warmed up, and therefore gives an inertia element. Thus the temperature will rise until all the losses are radiated or convected away by the ventilating characteristics and a steady heat flow is reached. This is very similar to the conditions in the electric circuit.

	Electric Circuit	Heating Circuit
Source of energy	Battery	Losses
Inertia element	Inductance	Mass x Sp.Ht.
Dissipative element	Resistance	Ventilation

Rise of current in electric circuit:- $I = \frac{E}{R}\left(1 - e^{-\frac{RT}{L}}\right)$ Equation 1

Rise of temperature in heat circuit:- $T = \frac{L}{K}\left(1 - e^{-\frac{Kt}{M}}\right)$ " 2.

T is temperature rise in °C.
t is time in minutes.
L are losses in watts.
K Ventilation constant.
M Mass x Sp.Ht. constant

For Equation 2 and the symbols of Equation 1 have their usual significan

The constants K and M for the motor must be determined by test. A continuous run is made at some load near full load and the final constant temperature noted. When t is large Equation 2 becomes:

$$T = L/K \quad \text{Hence:} \quad K = L/T$$

Therefore, the final temperature is given by K and the losses, or the constant K can be determined when the final temperature and losses are known, as in the special test.

The constant M is made from readings of rise during a short time run at overload. Equation 2 can be rewritten:

$$e^{-\frac{Kt}{M}} = 1 - (TK/L)$$

From which:

$$M = - (Kt)/\left[\log_e(1 - TK/L)\right]$$

The value of T in this equation is of course the temperature read at the end of the short run for time t. K is known from the previous constant temperature test and L is known from the measured constants or losses of the machine, so M can easily be calculated. It is possible to measure M during the first part of the constant temperature run, but the rate of rise is slow and so it is better to overload the machine so that practically normal full load temperature rise will be obtained in a few minutes to half an hour, giving greater accuracy.

The constant M is independent of speed, but K varies decidedly with speed, and so must be determined for each value of speed at which the machine is to run. A good way to do is to take several runs including extreme speeds and then plot a curve for K from which other values can be interpolated.

If the machine starts with an initial temperature T_1 T_o, Equation 2 becomes:

$$T = \frac{L}{K} + \left(T_o - \frac{L}{K}\right)e^{-\frac{Kt}{M}}$$

Example of determining constants:-

15 H.P. 500 Volt 600 r.p.m. D.C. Series Crane Motors.

Continuous Run	Speed	Total Losses	Temp. Rise.	K
	400	1695	79°C	21.5
	629	1815	70.5	25.7
	841	2330	78.0	30.0
(K interpolated)	0	0		12.0

One Hour Run.	Speed	Losses	Max. Temp.	K	M
	676	5750	73.5	26.6	3840
	522	5350	78.5	23.3	3340
				Average	3500

The losses in the one hour run do not check with the same speeds as in the continuous run owing to the necessity of changing the field strength to get overloads at approximately normal speed. Thus the equation of temperature rise for this motor can be written as below and from it can be calculated the temperature rise under any conditions of load. An efficiency curve is necessary in order to get the losses for each condition.

$$T = \frac{L}{K} + \left(T_o - \frac{L}{K}\right)e^{-\frac{Kt}{3500}}$$

(K being taken from continuous run data.
(L taken from efficiency curves.

Froelichs Equation will also be found to give approximate results for temperature rise curves under constant conditions, but does not give information which can be applied to other loads or cycles. This is written:

$$T = At/(1 + Bt)$$

Where T is the temperature rise at time t, and A and B are constants. If two successive readings are made during the rising part of the temperature curve, then the two values of A and B can be calculated and the final constant temperature rise will be given by A/B.

Westinghouse gives data covering the Time to Rise to 50°C above air for Fully Enclosed Motors The data is in the form of curves plotted between the total losses divided by the total outside area, giving Watts per Sq.Inch, and the Time in Hours. Points on the most useful curve are as follows:

Watts per Sq.Inch.	Time to Rise to 50°C.
3.00	0.16 Hours
2.00	0.24
1.00	0.66
0.80	1.00
0.55	2.00
0.46	3.00
0.42	5.00

VI. COUPLING TO LOAD:

1. DIRECT.- May be obtained by rigid or flexible couplings. Occasionally apparatus to be driven is mounted on same shaft as motor. Set may be two, three or four bearings. If two bearing rigid type of couplings must be used. If three bearing

rigid coupling also must be used and presents small amount of difficulty and required care in alignment. If four bearing, rigid coupling may be used, but is very difficult to get in perfect alignment, and therefore flexible coupling is preferable.

Flexible couplings must always be used where there is any doubt as to possibility of exact alignment. Only objections to flexible couplings are expense, wear of parts, and possibility of noise. None of these are as serious as rigid coupling badly aligned.

2. BELTS.- Belts are widely used due to their admirable characteristics; they are smooth running, quiet, cushion shocks and jars, allow motor to be placed various distances from load, allow change in speed between motor, and load, and form a sort of overload protection for motor and machine by slipping if machine jams or load is too severe.

Material	Ultimate Tensile Strength	Coefficient of Friction
Leather	3000-6000#/sq,in.	.30-.55
Rawhide	3000-6000	.30-.50
Fabric	6000-8000	.20-.35
Rubber	2000-4000	.30-.50

Working tension should not be greater than 320#/sq.in. due to excessive stretch for greater amounts. This is about 60 pounds per inch of width for average belts.

Weight of Leather Belting		Approximate Thickness
Single:	70#/in. of width	/16"
Double:	90#/" " "	5/16"
Extra Double:	120#/ " " "	7/16"

Minimum Pulley Diameter	Belt Thickness
4"	1/8"
6"	5/32"
9"	3/16"
12"	7/32"
18"	9/32"
30"	11/32"
48"	7/16"

Maximum speed ratio normally advisable is six to one. Greater than this requires idler pulley. The distance between centers of pulleys should not be less than twice the diameter of the larger one. Pulleys must be flanged or crowned to keep belt in place. Flat pulleys require forked guide for belt so that belt runs through

guide on to pulley. Arc of Contact should be made as large as possible. Less than 150° is unsatisfactory.

Formulae: Length of belt required, L. (Closely approximate).

$$L = \pi D/2 + \pi d/2 + 2\sqrt{x^2 + 1/4\ (D \pm d)^2}$$

D = Diameter larger pulley.
d = " smaller "
x = Distance between center lines of pulleys.
The minus under radical is for straight belts, plus for crossed belts.
The theoretical formula for power transmitted is:

$$H.P. = WtCVT(1 - mV^2/9660\ T)/33000$$

D = diameter large pulley - inches.
d = diameter small pulley - inches.
W = width in inches.
T = tension in driving side, #/sq.in.
t = thickness in inches.
V = velocity in feet per minute.
m = weight in lbs. per cu.in.

$C = 1 - e^{-nft}$ where - n = arc of contact/180° = $\dfrac{180-60(D-d)/L}{180}$

L = distance between centers - inches.

This is inconvenient for general use and approximate form is usually satisfactory. The following formula does not take into account centrifugal force for high belt speeds, which must be figured and subtracted from T.

$$H.P. = VWQB/33000$$

Q = 1 for single belt.
= 1.6 for double belt.
= 2.0 for triple or extra double belt.

B depends on arc of contact which is given as 180 - (D-d)4.75/L where D and d are inches and L feet.

B	Arc of Contact
28	90
34	112.5
41	135
48	157.5
55	180
69	225
83	270

Considerable diversity will be found between results by different formulae. 10 H.P. at 1200 R.P.M. with D = 24", and d = 6" gives belt widths for single belts from 2" to 6.67" by various formulae.

The proper one to use must be decided by judgment as well as theory, and wide range is often given because formulae do not take into account all data and really only fit small range of conditions.

Belt speeds of 3000 to 4500 feet per minute are limiting values for good practice. Below these values belting is used inefficiently and above it is difficult to obtain good drive on account of centrifugal force.

3. CHAINS. Silent chains of the Morse or Link Belt type are used in many places for connecting load. There is a little data available for calculating the size necessary as the manufacturers tabulate all data in their catalogues, and chain must be picked from their list of sizes rather than specially designed or fitted to load.

They have the advantages of positive drive, less space required than for belts with some power transmitted, more silent than gears, and allow easier adjustment of motor.

They have the disadvantage of requiring care to keep them in condition, and necessity of tightening as the links wear. The total weight of drive is heavier in most cases than belts or gears, and they are very noisy after the links wear badly, although this is generally caused by misuse rather than natural wear.

4. GEARS. Gears are used where large amounts of power are to be transmitted, where positive drive is necessary, and where large speed ratios are required. They may be of several types:-

a. Spur	d. Herringbone
b. Worm	e Mortise
c. Helical	f Bevel

The majority of industrial applications of moderate size use spur gears. Helical gears are adopted where silence is important and herringbone for large amounts of power. Mortise gear were formerly used in many applications where they are now superseded by the herringbone type.

Worm gears are used largely where very great reduction of speed are necessary.

With all types except worm the larger gear is usually made of steel, but the driving pinion may be of steel, bronze, rawhide, compressed cloth, micarta-duck, bakelite, and other combinations the object being chiefly to reduce noise, which is usually done at the expense of wearing quality.

The forms of the teeth may be either cycloidal or involute and, in some cases, of special curvature. The cycloidal type is theoretically better, and involves less friction, but has the disadvantage of requiring very close adjustment and alignment of gears. Largely due to better operation with worse alignment and somewhat

easier manufacturing conditions the involute gear is the type commonly employed.

Gears are classified by Pitch. This may be of several types:

<u>Circular Pitch</u>:	(Length of arc between two teeth at pitch line).
<u>Chordal Pitch:</u>	(Length of chord between two teeth at pitch line)
<u>Diametral Pitch</u>:	(No. of teeth divided by Pitch Circle diameter).
<u>Modular Pitch</u>:	(French method), Etc.etc.

The Circular and Diametral Pitches are the only ones commonly used in this country. Diametral Pitch is the commonest of these two and used almost exclusively practically, while circular pitch is simpler in dealing with the theory. There is naturally a simpler relation between them.

Diametral Pitch is equal to: π/Circular Pitch

Pitch Line speed in ft. per min. = Pitch Diam.(ins.)(r.p.m.)(0.2618)
Noise begins at Pitch Line Speed of 600 ft./min. with spur gears.

<u>Limiting Pitch Line Speeds</u>:

Cast Iron Spur	1800 ft. per min.
Cast Iron Helical	2400
Cast Iron Mortise	2400
Cast Steel Spur	2600
Cast Steel Helical	3000
Special Steels	4000
Herringbone in oil	5000
Rawhide,Cloth,etc.	2000 to 3000

<u>Efficiencies of one pair of gears:</u>

Spur	95%	These are average values and considerable variation both ways has been obtained.
Bevel	90%	
Herringbone	97%	

At 96 ft/sec. = 5760 ft/min., Pitch Line Speed, the centrifugal tension in spur wheel rim = 2000#/sq,in.

<u>Tensile Strengths of Materials</u>:

Chrome Vanadium Steel	Tempered	118,000-125,000#/sq.in.
" " "	Annealed	87,000
Nickel Steel		87,000
Carbon Steel		50,000-70,000
Phosphor Bronze		58,000
Wrought Iron		50,000
Cast Steel		45,000
Cast Iron		36,000
Rawhide, etc.		30,000 (approx.)

Formulae: The theory of gears is rather complicated and an absolutely correct formula very difficult to handle. The Lewis Formula covers all the essentials very well and meets most of the cases required. It is really a group of formulae to be combined for special cases.

$v = 0.262\ DR$ $\qquad W = SAY/P$

$S = s \times 600/(600+V)$ $\qquad H.P. = WV/33000$

Empirical Formula for face or width:

$$A = \frac{0.15\sqrt{V} + 9}{P}$$

D = Pitch Diameter in inches.
R = R.P.M.
V = Pitch line velocity in feet per minute.
s = Allowable Unite stress for material, Static.
(About 1/5 Tensile Strength).
S = Allowable unit stress for material at V.
A = Width or face in inches.
Y = Outline factor. Varies from .067 to .124 for 15° involute.
P = Diametral Pitch.
W = Maximum safe tangential load in pounds at Pitch Diameter.
H.P. = Maximum Safe Horsepower.

The width of the pinion should be equal to that of meshing gear plus the sum of the end play of both shafts. Flanges on pinion should never engage with meshing gear.

For Bevel Gears the mean pitch circle is taken and formula applied as above.

For Worm Gears $W = ACp$ where p = Circular Pitch (Approx.)
C = Constant
C = 285 - 425 for cast iron cut teeth.
= 455 - 711 for Phosphor Bronze and Hardened Steel Combination
(These values should be lower for continuous running)

For Helical Gears: $W = 0.0833\ Aps.\ \cos^2 x$ (approx.)
Where p is circular pitch as same as for Lewis formula and x is pitch angle of teeth.

5. 5. MISCELLANEOUS. Rope drive was at one time extensively used in textiles factories, but has been almost entirely superseded in modern mills by either individual or group electric drive. It is, of course, still used extensively in Hoisting and Elevator Service.

Friction Gearing is sometimes resorted to for flexible speed control, since the ratio between two friction plates driving through a right angle can be varied by extremely small amounts. It is not satisfactory except where this feature is very desirable or for extremely small amount of power where its simplicity makes it advisable.

There are many complicated combinations and special devices that are too varied or too limited application to take up in detail. An extreme case of special connection is the Waterbury Hydraulic Gear, used extensively on Battleships for Turret movements.

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VII. CONTROL.

Automatic Control is rapidly becoming a feature of many drives and applications. The control will not be gone into in detail as it would involve too much time. Special cases will be considered under the various applications. In general control is made up as follows:

1. Hand operated.
   a. Near Motor. Face plate or multiple knife switch type. Resistance for starting and field control or armature control. If resistance is for starting only it can be made smaller than for armature control. The resistances consist of wire wound bobbins bare or enameled, and grids for larger capacity. The face plate type usually carries no-voltage release and sometimes overload release.

b. Remote. In simple types a snap or knife switch is used to operate magnetic relays which make the main control connections. In more refined types a push button station or drum controller gives different combinations through magnetic switches. Sometimes a motor driven switch is used, controlled by push buttons. In a few large industrial applications electro-pneumatic switches are used, similar to multiple unit railway practice.

2. Automatic Control.
This consists of contactors, motor operated switches or solenoid operated switches, which complete a definite cycle after closing the starting switch. The cycle may be repeated indefinitely or stop after one operation. In machine tool or hoist applications, for instance, limit switches may stop the motor at a given spot, or start it on another part of the cycle. In some complicated cases various combinations are worked out, as in loading a blast furnace in steel mills automatic controllers are sometimes used to pick the right proportions of ore, coke and flux, dumping in a predetermined number of loads of each in a predetermined ratio.

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VIII. TYPICAL INDUSTRIES AND APPLICATIONS.

1. Mining and Ore Handling.

B. PUMPS:

a. Reciprocating.	Piston or Plunger Type. Single-Acting or Double-Actin Single, Duplex or Triplex. Direct Acting or Geared.
b. Centrifugal	Volute and Turbine Types. Vertical and Horizontal. Single or Double Inlet. Single Stage or Multi-Stage.
c. Rotary.	Bi-Lobular, Eccentric, Gear Types, etc.
d. Jet.	Air-Lift, Water Jet and Steam Jet.
e. Miscellaneous	Hydraulic Rams. Pulsometers, etc.

The Reciprocating and Centrifugal are the two types commonly used. The reciprocating type is very flexible in regard to capacity, head and speed, maintaining nearly uniform efficiency over a wide range. The centrifugal is small, light and cheaper for the same capacity than the reciprocating type, gives a steady non-pulsating flow of water but works best under one set of conditions for which it was designed, falling off in efficiency rapidly as these conditions are departed from. It therefore is generally used where it is required to pump a given amount of water continuously under a fixed head.

The rotary pumps are very inefficient and only used for small special applications where cost or efficiency is not an important factor.

The jet pumps, rams, and pulsometers are naturally not subject to electric drive and so will not be discussed.

GENERAL CONSIDERATIONS:

The problem of lifting a known weight of water at a known rate through a known height naturally gives a very definite theoretical H.P. required, which is divided by the hydraulic efficiency and mechanical efficiency of the pump in order to determine the size of motor needed. The losses are usually grouped as follows:

Hydraulic Losses:
1. Velocity head.
2. Entrance head.
3. Friction in Suction Pipe.
4. Losses in bends.
5. Losses in valves of pumps.

Mechanical Losses:
1. Friction in Bearings.
2. Friction of piston or plunger in cylinder.
3. Friction of piston or impeller churning in liquid.
4. Friction in stuffing boxes.
5. Friction of water in delivery pipe.

For convenience problems of pumping liquid are usually converted into terms of head, in feet. The vertical distance from the supply to the top of the discharge level is the total head. This divided by total head plus hydraulic losses gives the hydraulic efficiency. The mechanical efficiency is the theoretical H.P. required to lift the liquid through the total head (Measured) divided by the H.P. Input; This gives the overall efficiency and is most convenient for calculations. Sometimes the mechanical efficiency is calculated against the total head plus hydraulic losses, in which case it is higher than the over-all efficiency.

Suction lift:- Velocity usually designed to be 3 ft. per sec.
Then velocity head = 0.14 ft.
Entrance head = .07
Friction and Bends = 1.00
Suction valves = 1.50

Thus total suction loss is usually not more than 3 ft. head.

Altitude	Water head	Safe Working Suction Head
Sea Level	33.95 ft.	25 ft.
1320 ft.	32.38	24
2640 ft.	30.79	23
3960	29.24	21
5280	27.76	20
10560	22.82	17

Loss of Head Due to Fittings:

Size:-	1"	2"	3"	4"	5"	6"
Elbows	5	7	12	18	25	30 ft. head
Return Bends	10	14	24	36	50	60 " "
Globe Valves	6	8	20	30	40	50 " "

Loss of Head in Pipes:

Chezy Formula: $V = C\sqrt{Rs}$

V = mean velocity.
R = hydraulic rad.
= area/perimeter
= d/4 for circ.pipe.
s = loss head per ft.
C = 50 to 150.

Fanning Formula:- $s = 4f(1/d)(V^2/2g)$

d = diameter pipe, feet,
f = coeff. friction = .004 to .010(.006 Av.)
g = 32.2 ft. per sec. per sec.

These older formulas with variable constants are now being replaced by those with fractional exponents, such as:-

$$H = (0.38\ V^{1.86})/d^{1.25}$$

where H = loss head in ft./1000 ft.
V = vel. in ft./sec.
d = diameter in feet.

Horse-Power Required to Pump Water:

H.P. = (G X H)/(3960 X E) where G = gals. per min.
H = total head ft.
E = efficiency

Velocity head must always be included in total head. Given by formula:

$$h_v = V^2/2g$$

V = velocity in feet per sec.
h_v = head in feet
g = 32.2

The best velocity for discharge pipes is an economic problem in which the cost of pipe in balanced against the cost of power to overcome the losses. As the losses are reduced by larger pipe the cost is of course increased. The velocities usually used lie between 0.5 and 15 feet per second. Velocities of 2 to 3 feet per second are conservative and 6 feet per second is about the highest usually used.

Approximately:
One water H.P. = 4000 gals. feet per minute.

Also $H.P. = QdH/550$ where Q = cu.ft. per sec.
d = density.

Or: $H.P. = 144\ pQ/33000 = pQ/229 = pW/229\ w = HW/33000 = HwQ/33000$

or approximately $H.P. = pW/14{,}300 = HQ/529$.

p = pressure in lbs./sq.in. difference between inlet and outlet.
H = head in feet.
Q = quantity pumped in cu.ft. per min.
W = quantity pumped in pounds per minute.
w = weight per cu.ft. = 62.36 lbs. at 62°F.

Miscellaneous Information.

1 ft. head = 0.434 lbs. per sq.in.
Friction head proportional approximately to v^2 and length of pipe.
1 gal. water = 231 cu.ins. = 8.33 lbs.
1 cu.ft. water = 7.5 gals. = 62.5 lbs.
1 second foot of water = 7.5 gals. per sec. = 450 gals. per min.
1 acre foot of water = 325,850 gals.
Density of sea water = 1.026

Velocity in pipes: $V = 0.408\ G/d^2$

d = diam. pipe in ins.
G = G.P.M.
V = ft. per sec.

Weight of water in lbs. per yard in pipes is within 2% of d^2 when d is given in inches.

Volume of pipe: $= .000455\ d^2 l$, cu.ft. d in inches.

$= .0034\ d^2 l$, gals. l in feet.

RECIPROCATING PUMPS:

For small sizes a single double-acting pump is belted to the motor with an idler pulley. Air dome is provided to take up shock of pulsations. One of the most popular combinations is a triplexsingle-acting pump gears to the motor. Owing to the low speed of reciprocating pumps, which seldom exceeds 100 r.p.m. and the liability of getting wet, belts are seldom used for pump connections except in very small sizes. Also owing to low speed, direct connection is never used, and the motor is in almost all cases geared to the load.

In addition to allowing for the efficiency of the pump, the "Slip" must be allowed for, which is loss of volume by water passing the plunger packing or the valves. Under good conditions the slip is about 3-5 per cent, but under bad conditions may rise to 10 or 15 per cent. New pumps are usually tested to show not more than 1 per cent.

The efficiency varies from 50 to 90 per cent. 75 per cent is a fair average, but if the application contains many uncertain points, 50 per cent should be used for safety.

The volume delivered by a pump not allowing for slip, is -

$G = d^2 P/24.51$

G = gals. per min.
d = plunger diam. in ins.
P = plunger speed in ft. per min.

The allowable stresses in material for pumps are lower than for most machines due to danger of water-hammer. Safe tensile stresses are about:

Cast Iron	= 1500-1800 lbs. per sq.in.
Cast Steel	= 5000-8000
Bronze	= 3000
Forged Steel	= 10,000

CENTRIFUGAL PUMPS.

Operate by developing centrifugal force in the water by a rotating impeller carrying vanes. The casing may contain vanes also, in which case it is called a Turbine Pump, or may be merely a spiral casing in which case it is called a Volute Pump.

Low pressure pump for 50 ft. head or less.
High pressure pumps for more than 50 ft. head.
150 to 200 ft. head is the limit for one impeller.

Low speed less than 600 r.p.m. Steam or Electric Drive.
Medium speed, 600-1800 r.p.m. Chiefly Electric Drive.
High speed, more than 1800 r.p.m. Turbine and Electric

Single Inlet, causes end thrust, but simple to make.
Double Inlet, balances end thrust but difficult to pack.

Radial Discharge. Used for high pressure.
Backward Discharge. Most common type.
Forward Discharge. Unusual.

For Radial Discharge of common design it can be shown theoretically that -

$H = v^2/g$ H = head in feet
v = Periph. vel. impeller edge ft. per sec.
g = 32.2 ft./sec./sec.

Power Losses: Ring Oiled Bearings.

$F = .002\ dNW$ F = foot-lbs. per min.
d = shaft diam. ins.
N = r.p.m.
W = total weight on bearing.

Thrust Bearings.

$F = .005\ W_t\ (d + d_1)\ N$ W_t = thrust in lbs.
d_1 = outer diam. collar.

Impeller Friction in Liquid.
(Majority of losses)

$H.P. = 1.25(v/100)^3\ D^2\ S\ s$ v = periph. spd. ft./min.
D = out. diam. impeller ft.
S = No. of stages.
s = Sp. Gr. of liquid.

Short Circuit loss.

Negligible at full load 25-30 per cent of rated load at no load.

Shaft Efficiency - 70-80 per cent 88% has been reached, but exceptional.

For average pumps the most efficient combination is found when

$$G.P.M. \times \text{Head in feet} = 400 \text{ to } 600 \times 10^3$$

For any one pump $Q/\sqrt{H}$ or $G/\sqrt{H}$ may be taken as constant which will allow change of rating for best conditions. As $\sqrt{H}$ is proportional to N, we can also write:

$$Q/N \text{ or } G/N = \text{constant}$$

The inlet velocity on centrifugal pumps is somewhat higher than on reciprocating types, and may run from 6 to 12 ft. per sec. There are usually 6 to 12 impeller blades, and half as many discharge vanes.

Suction Pipe. $(H_s^1 + h + V^2/2g) = H_s$

H_s^1 = suction head. Which gives the total equivalent suction head H_s and this value must not exceed

h_2 = friction head. the safe suction head for corresponding altitude given in tables above, or, in general,

$V^2/2g$ = vel. head. be made less than 23 ft.

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COMPRESSORS OR BLOWERS

Types:

1. Fans. Working pressures 1/8 to 16 ozs.
2. Jet Blowers.
3. Rotary Blowers. Pressures 1 to 10 lbs.
   a. Positive Pressure.
   b. Positive Volume.
4. Centrifugal Blowers or compressors. Working pressures 5 to 10 lbs. Sometimes 100#
5. Piston compressors.
   a. Single Stage. 1 to 100 lbs.
   b. Two Stage. 80 to 500 lbs.
   c. Three Stage 400 to 1200 lbs.
   d. Four Stage 1000 to 3000 lbs.

USES OF AIR.

1. Ventilation.
2. Transmission of power.
3. Forced draft.
4. Carrying away gasses, shavings, dust, etc.
5. Locomotives.

CONSTANTS OF AIR:

Under normal average conditions 1 cu.ft. dry air weighs .0727#

1 cu.ft. saturated air .073 to .075.

At average room temperature and normal air pressure, the specific heat of air is- Dry, 0.242; Saturated, 0.245.

These constants do not vary from these amounts enough under compression and other handling to cause very large errors in results, and while theoretically not correct to do so, it is satisfactory for general calculations for the purpose of estimating power requirements, to consider them constant under all usual conditions.

Calculations of air handling and compression are always based upon cubic feet of free air, that is at normal atmospheric pressure.

Heat is developed air is compressed. Heat is absorbed when air is expanded. Therefore cooling of compressors must be furnished and intercooling between stages on multi-stage compression. Likewise when air is used for developing power it is far more efficient to pre-heat the air before expanding, and also prevents the moisture freezing in engines, etc.

AIR CONSUMPTION OF VARIOUS TOOLS:

The amount of air for a number of similar tools in parallel is less than the product of the number of tools times the air for one. This is due to less waste and diversity factor. The decrease is in proportional to 20% for 10 in parallel, and 50% for 100. An increase of air is required for high altitudes, about 25% more being needed at 8000 feet. The following figures are based on an air pressure of from 70 to 90 lbs. gage.

Rock Drills.	2"	3"	4-1/4"	5-1/2"
	70	130	175	220 cu.ft. free air/min.
Small Paint Sprays			2 to 3	" " "
Hand Grinders, 20# size			20	" " "
Riveters			5 to 6 cu.ft. per rivet.	
Hand Riveters:		13#	20#	25#
		16	22	25 cu.ft./min.
Surfacers		30 to 60 cu.ft. per min.		
Chipping Hammer		5#	10#	15#
		6	15	20 cu.ft./min.
Hoists	1 ton	2 ton	4 ton	8 ton.
	3	6	10	25 cu.ft./ft. of lift.
Motors	2 H.P.	4 H.P.	8 H.P.	15 H.P.
	45	70	125	240 cu.ft/min.
Rotary Drills	10#	30#	50#	75#
	15	25	40	48 cu.ft./min.

Sand Blast-nozzle	3/16"	1/4"	3/8"	1/2"
Sand per hour	500	900	1700	3000 lbs.
Cu.ft. air per min.	45	85	190	340

Carving Tools (Stone)	1#	2#	4#	9#
	3-6	4-7	6-9	12 cu.ft./min.

Wood Boring	10#	15#	30#	
	15	20	25	cu.ft./min.

Comp. Air Locomotives: Supply in cylinders at 800#/sq.in. Reduced to 150 to 250 lbs. for use. Best efficiency with compound engines, preheated, and reheated between cylinders. Advantageous where handling explosives, or in explosive gasses, and electric wiring inconvenient.

FANS: Propeller Type. Very poor for forcing air through pipes or ducts. Used chiefly for exhausting air from rooms. Should have clear air space on both sides. In small sizes used for circulating air in rooms. Fans are made in sizes from 8" to 42" diameter. It is difficult to figure the theoretical H.P. required to drive fans since there are so many variables. Speeds are usually relatively low due to large amount of noise caused at high speeds from tearing of air. Centrifugal blowers are sometimes called fans when operating at low speeds. Here we consider a fan of propeller type only. The speeds vary from 1800 r.p.m. for desk fans down to 200 r.p.m. for large sizes. The characteristics are usually specified as air delivery in cu.ft. per minute and pressure in inches of water as measured by a manometer. The H.P. of a propeller fan may be roughly taken as:

$$\frac{\text{Cu.ft. per min.} \times \text{inches of water}}{1500}$$

This is by no means exact, but gives a rough estimate. Inches water for free delivery should be taken as .09.

The energy in a moving column of air may be expressed as:

$$\text{H.P.} = VAP/33000 = QP/33000 = 5.2\,Qh_i/33000 = 0.1728\,Ah_i\sqrt{h/W}$$

Also:

$$V = 956\sqrt{(460 + t)\,h/B}$$

1 oz. per sq.in. = 1.732 ins. water.

Where:
- V = velocity ft. per min.
- A = area, sq.ft.
- P = pressure, lbs. per sq.ft.
- Q = volume, cu.ft. per min.
- h_i = impact head, inches of water.
- h = velocity head, inches of water.
- W = weight of air, lbs. per cu.ft.
- t = temperature, deg. Fahr.
- B = barometer inches mercury.

JET BLOWERS. Not subject to electric drive.

ROTARY BLOWERS. Can be arranged to maintain constant pressure irrespective of other conditions, or constant volume. The latter is convenient for such applications as blast furnace work, where constant volume of air can be furnished regardless of caking of charge. As with rotary pumps, they are generally of bi-lobular, gear, or eccentric types. The efficiency is low and they are not satisfactory for more than small heads or pressures. Reduction in outlet greatly increases H.P. If totally closed blower may be wrecked or motor burned out. The H.P. required is thus largely a matter of conjecture and judgment, depending upon expected conditions. It is customary to allow five H.P. for every 1000 cu. ft. of air pumped against a pressure of 16 oz. per sq.in.

CENTRIFUGAL BLOWERS. These may be simple affairs of paddle wheel type with spiral casing, or more careful designed type with impeller and discharge vanes carefully formed. They are very successful for carrying large volumes of air against moderate heads, and through ducts or pipes. Thus admirably adapted to all manner of ventilation work, forced drafts, forge blowers oil burning, etc., though not commonly used for compressors for higher pressures required by air tools, etc.

The volume of air delivered varies directly with the speed.
The pressure of air varies with the square of the speed.
The horsepower varies as the cube of the speed.

A formula for calculating the power necessary is:

H.P. = $5.2\,Qh_i/33000\,E$ where E is efficiency and others as above.

This is correct where E is known. Average values of E are:

Steel Plate Type	0.50
Sirocco	0.65
Cone Type	0.45

Restriction of inlet or discharge openings reduces the power required. This method is used for unloading when starting large fans driven by synchronous motors. The motor is usually direct connected as speeds are relatively high and can be designed easily to fit motor speeds of normal value.

Centrifugal Compressors may be classified as:
a. Single Inlet, or Double Inlet.
b. Single Stage or Multi-Stage.
c. Forward, Radial and Backward discharge.
d. Low pressure, (1-5 lbs.) High Pressure (Above 5 lbs.)
e. Radial Inlet, or Axial Inlet.

A blower or compressor can be used with same efficiency for any one model when the Compressor Constant is the same.

Compressor Constant $= Q/\sqrt{P_2 - P_1}$ where P_2 and P_1 are final and initial pressures.

PISTON COMPRESSORS. These may be of low pressure type which are called blowing engines, but are practically superseded by centrifugal blowers for this purpose. Their chief field is compressing air in tanks to high pressures for many purposes, furnishing air for various air tools, etc.

They may be Direct Connected, Belted or Geared to the Motor. Smaller sizes are usually belted, and the larger sizes direct connected. They must be provided with unloading device for starting when connected to synchronous motors. Small rugged duty compressors for garage service and similar applications are often geared to the motor, as large reductions must be obtained in small space.

The compressor speeds vary from 80 to 700 r.p.m.
The average piston speed varies from 300 to 500 ft. per min.

$$M.E.P. = P_1 \left[\frac{Sn}{n-1} \left[(P_2/P_1)^{\frac{n-1}{Sn}} - 1 \right] \right]$$

$$H.P. = M.E.P. \times L \times A \times N/33000$$

P_1 = initial pres. lbs. abs.
P_2 = final.
S = no. stages.
n = exponent of compression curve = 1.35 approx.
L = stroke
A = piston area
N = strokes per minute

Volumetric Efficiency averages 80 to 97%.
Apparent volumetric efficiency obtained from indicator card.
True volumetric efficiency ratio of air actually pumped to piston displacement.
Cylinder Efficiency is work to compress piston displacement isothermally divided by actual work done in cylinder. Averages 80 to 85%.
Efficiency of Compression is Cylinder Eff/True Vol. Eff. 64-82%.
Mechanical Efficiency is work in air cylinders/work delivered to shaft. Averages 76 to 97%.
Over-all Efficiency is Mech.Eff. x Eff. of Compression, and averages 48 to 79% with 56% a fair average.

For figuring power required to compress a given volume of air we have:

$$H.P. = (144/33000)(n/n-1)\, P_1 V \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right]$$

where V is volume of free air compressed per minute. Others as before.

This gives value too high for multi-stage compressors if efficient intercooling is used. The power and capacity also decrease with altitude but not in same proportion. At 8000 feet the capacity has decreased to 76% and H.P. to 35% of that required at Sea Level. It can be assumed directly proportional to altitude without serious error.

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VIII. A. HOISTS CRANES AND ELEVATORS.

As the general problem of hoisting involves the same points of consideration in its many variations of application only one type of hoist will be considered. The high-speed Mine Hoist is chosen, as it magnifies the effect of the many features that must be considered.

There are two general classes of mine hoists.

1. Metal Mines. Usually operating several levels, shafts from 1000 to 4000 feet deep. Generally slower and more intermittent.
2. Coal Hoists. Usually only one level, 300 to 600 feet deep, and very high duty cycle with uniform uninterrupted operation.

Shaft Mines are those having a vertical or nearly vertical shaft with drifts run off sideways at operating levels.

Slope Mines are those whose shaft runs into the side of a hill and usually follows the ore seam directly.

The shafts may be operated either unbalanced or balanced. That is two cages and sets of guides may be provided, one going up as the other goes down. Where there is only one cage, artificial balancing is seldom used. The cages may be self dumping at tipple, or car may be run off by hand. In slopes hoist cars are used instead of cages. With less than 3.5% grade a tail rope is used to pull down empties. With grades less than 3% locomotives are probably better than hoists.

A maximum rope speed of 3500 feet per minute for shafts and 1200 ft. per min. for slopes is common practice.

Four seconds is considered the minimum stop between cycles for loading and unloading the cages. For deep shafts or long hauls 10 to 20 secs. used for acceleration and retardation; 5 secs. is the minimum advisable. Retardation can usually be accomplished in less time than acceleration.

The hoist rope is wound over drums or reels. The drums may be Cylindrical, Conical, or combination of the two. With reels the rope must be flat and winds on in layers. Conical drums and reels give the advantage of low starting torque, as rope on small radius, and high retarding torque at end of hoist, due to large diameter. Cylindrical drums more readily permit winding rope on in layers, and with electric drive are usually more satisfactory, as motor can take care of peak starting load better than a steam engine. For single level mines the drums are usually fixed to shaft. For multi-level operation one or both drums are clutched to the shaft. Hand controlled brakes are always furnished for the drums. The "Fleet Angle" of the rope must be less than 5 degrees, and so for confined space the reel type is sometimes advantageous. but cylindrical drum generally preferable where no unusual features prevent its use. Drum and Sheave diameters are never made less than 60 times rope diameter.

All large hoists are direct connected, and are known as "First Motion". If not direct connected, motors are geared with Herringbone Gears and are called second or third motion hoists depending on the number of reductions. Third motion only used in very small sizes. Second motion used where only A.C. available and induction motors must be used. Pinion is made part of hoist mechanism, and motor coupled by flexible coupling.

For large hoists Ward-Leonard or Ilgner-Ward Leonard Control is used. This consists of a Motor Generator, with or without Flywheel, which furnished D.C. for operating the motor driving the hoist, and all control is obtained through the Generator field. By means of the flywheel and slip regulator the power demands from the line may be equalized and reservation charges by central station reduced to a minimum.

The weight of the rope is a very considerable part of the total load. Tables of J. A. Roebling & Co. 1915, giving weights and sizes of plow steel rope, 6 strands, 19 wire hemp center, can be approximated very closely by taking the weight in lbs. per foot. as $= 1.08 \times 10^{-4} \times$ load in lbs.

FRICTION LOSSES.

Hoist Mechanism Efficiency: $E = w/(w+kW)$ (First Motion)
(Approximate Value)

Second Motion - .95 E
Third Motion - .90 E

$W = (w + 2\ ws + wr) \sin \phi$ For balanced vertical and inclined shafts.

$= (w + ws + 0.5\ wr) \sin \phi$ For unbalanced vert. & inclined shafts.

$= (w + q\ ws + wr) \sin \phi\ (w + 2\ ws)\ 0.2 \cos \phi + 0.1\ wr \cos \phi$
For balanced slope hoist.

$= (w + ws + 0.5\ wr) \sin \phi + (ws + w)\ 0.02 \cos \phi + 0.05\ wr \cos \phi$
For unbalanced slope hoist.

k = 0.05 for vertical.
k = 0.05 for vertical and 0.04 for slope hoist.
Above does not include rolling or rope friction.

Car friction assumed 40 lbs. per ton normal pressure.
$0.02\ (ws\ wr) \cos \phi$
Rope friction assumed 200 lbs. per ton normal pressure.
$0.10\ wr \cos \phi$

w = weight of one load in lbs.
ws = weight of one cage in lbs.
wr = weight of rope per side.
ϕ = angle of shaft with horizontal.

CHECK: Check may be obtained as the net work done on material in H.P. seconds divided by the net work in output duty cycle should equal the mechanical efficiency.

Also H.P. seconds for acceleration and retardation should be equal.

HOIST THEORY: The load cycle must necessarily be divided into three parts: Acceleration, constant speed and retardation.

Each of the forces during these three parts may then be conveniently considered separately.

a. Inertia Forces.
b. Work against gravity.
c. Friction loss.

<u>Note</u>: The following formulae are developed for balanced hoisting. For other conditions they must be modified to correspond.

ACCELERATION: Inertia Forces. Acceleration assumed uniform.
$f = ma \quad a = V/ta \quad m = Wa/32.2 \quad$ thus: $f = WaV/32.2\ ta$

Ft. lbs. per sec. are $fv = fV$ (max.)

To this must be added the friction H.P.

CONSTANT SPEED. The acceleration forces disappear. Friction and direct work against gravity only work required.

By the same methods of reasoning the H.P. becomes:

$$H.P. = (V/550)(w + Lp) - Vtap - 2Vpt)$$

As before,

V is rope speed in feet per sec.
w weight of load in lbs.
ta time for acceleration in seconds.
t instantaneous time from <u>beginning of constant speed</u>.

It will be seen that it is a straight line of negative slope.

RETARDATION. The inertia forces now reverse in sign and are of the same general form except that tb is substituted for ta.

Load, cages and rope - $H.P. = -WV^2/32.2 \times 550 \times tb$ (Max.

Motor and gears - $H.P. = -4g^2WV^2r^2/32.2 \times 550 \times D^2 \times tb$(Max.)

Drums and sheaves - $H.P. = 0\text{-}4\ WV^2r^2/32.2 \times 550 \times D^2 \times tb$ (Max.)

<u>Hoisting Power</u>.- The maximum value of this will be same as the minimum value during constant speed section, and it will be very closely approximated if it is assumed to decrease in a straight line to zero when hoist is brought to rest.

$$H.P. = (w+Lp)V/550 - V^2(tap+2\ tsp)/550 - (w+Lp-Vtap-2Vtsp)Vt/550tb$$
$$-V^2t^2p/550tb + V^2pt^3/tb^2550$$

where t is again instant time from <u>beginning of retardation period</u>.

FRICTION. The friction losses cannot of course be accurately estimated. For vertical hoists they can be taken as -

$$H.P.\ loss = H.P.\ (1-E)/E$$

where E is value found for mechanism efficiency decreased about 2-5% for guide and rope friction, and H.P. is value at beginning of constant speed hoist period. For slope hoists the pull necessary must be calculated for the weight of cars and ropes, etc. and H.P. figured from PV/550 where P is pull, V rope speed in ft. per sec.

They are usually assumed constant losses during constant speed part of hoist, and decreased during acceleration and retardation periods in straight line to zero at beginning and end of cycle.

MOTOR H.P. After establishing the load cycle, the r.m.s. H.P. is determined to find the required rating of motor. This may be figured from the load curve, by constructing it with ordinates of H.P. squared or may be approximated by formulas such as the following:

If A is peak H.P. at end of acceleration period.
B is H.P. at beginning of constant speed period.
C is H.P. at end of constant speed period.
D is negative peak at beginning of retardation period.

r.m.s. H.P. for Induction Motor.

$$H.P. = \sqrt{\frac{A^2\ ta + \frac{B^2 + C^2 + BC}{3} \times ts + D^2\ tb}{ta/2 + ts + tb/2 + tc/4}}$$

For D.C. Motor:

$$H.P. = \sqrt{\frac{A^2\ ta + \frac{B^2 + C^2 + BC}{3} \times ts + D^2\ tb}{3\ ta/4 + ts + 3\ tb/4 + tc/2}}$$

where ta, tb, ts are as before and tc is time between cycles, D.C. Motor can be slightly smaller owing to its better radiation of losses. A and D must include the power to accelerate armatures and all inertia parts.

For armas. $H.P.\ (max) = \left[Wr^2\ (r.p.m.)^2 \times 0.62\right]/(ta \times 10^6)$

MINE HOISTS - METHODS OF CONTROL.

Speed control of hoist motor may be obtained by rheostatic methods, which are usually inefficient. For large hoists the Ward-Leonard-Ilgner system is usually employed. A motor generator set driven by wound rotor induction motor furnishes D.C. power at about 600 volts. All speed control of the hoist motor is accomplished by field control of the D.C. Generator. A separate exciter is used to supply current for fields of both generator and hoist motor. A fly-wheel on the motor-generator set supplies the peak loads, and evens up the demand on the A.C. power lines, so that almost uniform load is drawn from the Central Station and a reservation charge eliminated. The slip on the induction motor is con-

trolled by a slip regulator which varies the resistance in the rotor circuit proportionally to the load in such a way that the fly-wheel becomes most effective. The amount of slip allowed is usually 15%. The question of the amount of slip, fly-wheel weight, etc., is a very complicated one as it involves so many economic features. A large fly-wheel increases first cost, friction losses, etc., while a small one requires more peak load from the line, and greater slip on the motor, thus increasing charges and lowering efficiency. Each case must be treated for its special conditions.

Having obtained the root-mean-square H.P. required for hoisting from the load diagram, the motor losses for the rating adopted are then added to the load diagram and a new root-mean-square value obtained, which gives the generator rating necessary. The generator losses are then in turn added to the load diagram and the average H.P. determined. This time a first power average. The fly-wheel must deliver all power above the average line, and absorb all power below the average line. The power available, or absorbed from the fly-wheel is thus obtained in H.P. seconds. For a solid plate wheel the radius of gyration is 0.707 times the actual radius. The peripheral speed of fly-wheel is usually taken at 20,000 feet per minute. Then the velocity of the radius of gyration is 20,000 x 0.707/60 = 236 feet per second.

With a slip of 15% the peripheral velocity of the radius of gyration will be reduced to 200 feet per second.

From the considerations of Kinetic Energy the formula for fly-wheel weight then becomes:

$$\text{Weight} = \text{H.P. secs.} \times 550 \times 64.4/(236^2 - 200^2)$$

Or more generally any two velocities may be substituted in the denominator.

Having thus determined the hoist motor size, the generator size, and the fly-wheel weight, it only remains to find the A.C. motor rating necessary to drive the motor-generator set, and the application is complete.

As the motor load is almost uniform it is of course based upon the average H.P. of the load curve including losses of motor and generator. To these may be added the fly-wheel losses, the excitation power, required to drive the exciter, and the slip loss, which is taken as 1/2 the maximum slip times the average load. The only one of these indeterminates is the fly-wheel loss, which may be rather large. No very definite data is available on this subject, but roughly it may be taken as about equal to from 50 to 75 per cent of the losses in the generator.

The maximum peripheral speeds of fly-wheel of different materials are:

Cast iron	10,000 feet per minute
Cast steel	12,000 " " "
Special Cast Steel	22,000 " " "
Laminated steel	30,000 " " "

The laminated wheels are not used except where necess for some special reason, due to their high cost.

The Ward-Leonard system may be operated without fly-wheel in which case the over-all efficiency is somewhat higher, but the motor must be larger to carry the peaks; the peaks are also required from the power supply and will probably result in a higher power rate, and in case of power failure a hoist cannot be completed, as with the fly-wheel type the fly-wheel usually contains enough energy to complete a hoist started, even if the power line is disconnected. The efficiency is higher due to the elimination of the fly-wheel losses and the slip losses. The first cost may be more or less depending upon the relation of the fly-wheel cost to the increased cost of the A.C. motor.

There is an A.C. system with an equalizer set where hoist motor is A.C. and offers some advantages, but is not used to a great extent. The hoist motor is a wound rotor induction motor, and is connected directly to the lines and controlled by resistance in the rotor circuit. A synchronous converter is then also coupled to the lines, and the D.C. side connected to a D.C. motor driving a fly-wheel. A regulator controlled by the current in the power supply lines varies the field strength of the D.C. motor so that the energy in the fly-wheel is used to pump back through the synchronous converter and carry the peak loads. The criterion of use lies in the losses in the starting resistance in the hoist-motor rotor circuit. It probably would be very inefficient for short hoists that had cycles consisting largely of acceleration and retardation, and would be best on hoists having long times of operation at full speed.

The equipment used in some of the big copper mines is as follows:

	Depth ft.	Angle.	Wt. Ore p. trip	Rope Spd. ft/min.	D.C.Mot. H.P.	Gen. H.P.	A.C.Mot. H.P.	Fly Wh.
North Butte	4000	90	15,000	2700	2,000	1500	1400	100000
Canadian Copper	1500	55	18,000	2500	1,850	1500	1400	100000
Elm Orlu	3500	90	10,000	2500	1,800	1300	1150	92000
Butte & Superior	4000	90	16,000	2270	2,000	1500	2000	120000

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Vol. 34, p. 196, 1915.

HOIST CALCULATIONS

Neg. ____________

Customer ______________ Date ____________

General Data

Depth of shaft	
Angle of slope	
Net Weight of Load	
Weight of cage (skip)(not)self dumping	
Weight of car	
Size of rope	
Balanced: (Unbalanced)	
Size and shape of drums	
Weight of drums & Radius of gyration	
Max.Capacity required per hour	
Normal capacity required per hour	
Maximum number of trips per hour	
Total time for trip	
Time for cageing	
Running time per trip	
Total rev. of drum	
Maximum drum speed	
Maximum rope speed	
Increase in diameter per revolution	

Power Supply A.C. - D.C. ______Volts ______ Cycles ______Phase

TIME

Acc. in ____Sec. Const.speed _____Sec. Ret. ____________Sec.

Distance during Acc., ____________
Distance during Ret., ____________
Distance during const. speed ____________
Total Distance ____________

INERTIA:

Drums ____________
Sheaves ____________
Motor ____________
Load ____________

Total Flywheel Effect ____________

Friction assumed at ____________

CALCULATION OF LOAD DIAGRAM.

Acceleration: Inertia Forces _ _ _ _ _ _ _ _ _H.P.Max.
Work against Gravity _ _ _ _ _
Friction Loss _ _ _ _ _ _ _ _ _ TOTAL: _ _ _ H.P. Max.

Constant Speed: Work against Gravity _ _ _ _ _Start.
Friction Loss _ _ _ _ _ _ _ _ _Start. TOTAL: _ _ _ H.P. Start
Work against Gravity _ _ _ _ _Finish
Friction Loss _ _ _ _ _ _ _ _ _ _Finish " _ _ _ H.P. Finish

Retardation: Inertia Forces _ _ _ _ _ _ _ _ _H.P.Max.
Work Against Gravity _ _ _ _ _
Friction Loss _ _ _ _ _ _ _ _ _ TOTAL _ _ _H.P. Max.

LOAD DIAGRAM:

Acceleration Time: _ _ _Secs. Max.H.P. at end Accel. _ _ _ _ _ _ _H.P.
Constant Spd. Time: _ _ _Secs. H.P. at start of Constant Spd. _ _ _ _ _ _ _ _ H.P.
H.P. at finish of Constant Speed _ _ _ _ _ _ _ _ _ H.P.
Retardation Time: _ _ _Secs. H.P. at beginning of Retardation _ _ _ _ _ _ _ _ _ H.P.
Loading Time: _ _ _Secs.

HOIST MOTOR SIZE.

Root Mean Square value hoist diagram: _ _ _ _ _ _ _ _ _H.P.
Motor size calculated by formula: _ _ _ _ _ _ _ _ _H.P.

INPUT WITH RHEOSTATIC CONTROL.

Total Input to Hoist: _ _ _ _ _ _ _ _ _ _ _ _ _ _H.P. Secs.
Average Efficiency of Motor: _ _ _ _ _ _ _ _ _ _Per cent.
Total Input to Motor: _ _ _ _ _ _ _ _ _ _ _ _ _ _H.P.Secs.
" " " " _ _ _ _ _ _ _ _ _ _ _ _ _ _K.W.Hrs.
Shaft Output in load: _ _ _ _ _ _ _ _ _ _ _ _ _ _H.P.Secs.
Overall Efficiency: Shaft/Motor Input--H.P.Secs. _ _ _ Per cent
K.W. Hours per Ton: _ _ _ _ _ _ _ _ _ _ _ _ _ _

WARD-LEONARD SYSTEM

VOLTAGE CONTROL WITHOUT FLY WHEEL

Hoist motor output, Hoist motor input, Generator input, A.C. Motor input

1 _

2 _

3 _

4 _

5 _

Power input from line

Acceleration _ _ _ _ _ _ _ _ _ _ _ _ _

Constant speed _ _ _ _ _ _ _ _ _ _ _ _

Retardation _ _ _ _ _ _ _ _ _ _ _ _

Total ....= ====================

Constant losses,

Excitation of motor and generator _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ hp.

Friction of windage of generator _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ hp.

Iron loss of driving motor = ==============================

Total constant losses...=========================hp.

" " " in H.P. Seconds ==============

Total input = _ _ _ _ _ _ _ H.P. sec. = _ _ _ _ _ _ _ KW hr.

Overall efficiency= _ _ _ _ _ _ _

K.W.hrs per ton. = _ _ _ _ _ _ _ _ _ _

Capacity of generator

Capacity of A.C. Motor.

For hoist motor use _ _ _ _ _ _ _ _ _ _ _ _ _ _

For D.C. Generator use _ _ _ _ _ _ _ _ _ _ _ _

For A.C. Motor Use _ _ _ _ _ _ _ _ _ _ _ _ _ _

WARD-LEONARD-ILGNER SYSTEM

VOLTAGE CONTROL WITH FLY WHEEL

Hoist Motor output   Hoist Motor input   Generator input

1. _
2. _
3. _
4. _
5. _

Input to generator _ _ _ _ _ _ _ _ _ _ _ H.P.Sec.
Input

Average input to generator _ _ _ _ _ _ _ _

Time _ _ _ _ _ _ _ _ _ _

R.M.S. Generator Output _ _ _ _ _ _ _ _ _ _ _ _

R.M.S. Generator Input _ _ _ _ _ _ _ _ _ _ _ _

SIZE OF FLY WHEEL:

Input to fly wheel.

Acceleration ...._ _ _ _ _ _ _ _ _ _ _ _
Constant speed .... _ _ _ _ _ _ _ _ _ _ _ _

Total input .... _ _ _ _ _ _ _ _ _ _ _ _

Normal speed of set _ _ _ _ _ _ _ _ _ _ _ _ _ _ RPM
Dia. of fly wheel _ _ _ _ _ _ _ _ _ _ _ _ _ _ Ft.
Peripheral speed _ _ _ _ _ _ _ _ _ _ _ _ _ _ Ft.per min.

Normal speed at rad. of Gyration _ _ _ _ _ _ _ _ _ _ ft.per sec. = V_2

Speed at rad. of Gyration, 15% speed reduction _ _ _ _ _ft. per sec. = V_1.

$$\text{Weight of fly wheel} = \frac{\text{HPS} \times 550 \times 64.4}{V_2^2 - V_1^2} = \_\_\_\_\_\_\_\_\_\_\_\_$$

Use _ _ _ _ _ _ _ _ _ _ _ _Lbs. wheel, Thickness _ _ _ _ _ _ _ _ _ _

SIZE OF DRIVING MOTOR:

Average output	_ _ _ _ _ _ _ _ _ _ _ _	H.P.
Average input	_ _ _ _ _ _ _ _ _ _ _ _	H.P.
Motor & Generator excitation	_ _ _ _ _ _ _ _ _ _ _	
Windage and friction of generator	_ _ _ _ _ _ _ _ _ _	
Fly wheel loss	_ _ _ _ _ _ _ _ _ _	
Slip regulator loss	_ _ _ _ _ _ _ _ _ _ _	
	==================	

Total output of motor .... _ _ _ _ _ _ _ _ _ _ _ _

Efficiency of Motor, _ _ _ _ _ _ _ _ _ _ _ _

$$\text{Input to motor} = \frac{\text{H.P. Sec.}}{\text{Efficiency}} = \_\_\_\_\_\_\_\_ \text{ H.P.Sec.} = \_\_\_\_\text{K.W.Hrs.}$$

Overall efficiency = _ _ _ _ _ _ _ _ _= _ _ _ _ _ _ _ _ _ _ _ _ _

Kw. hrs. per ton = _

Capacity of Generator =

For hoist motor take,

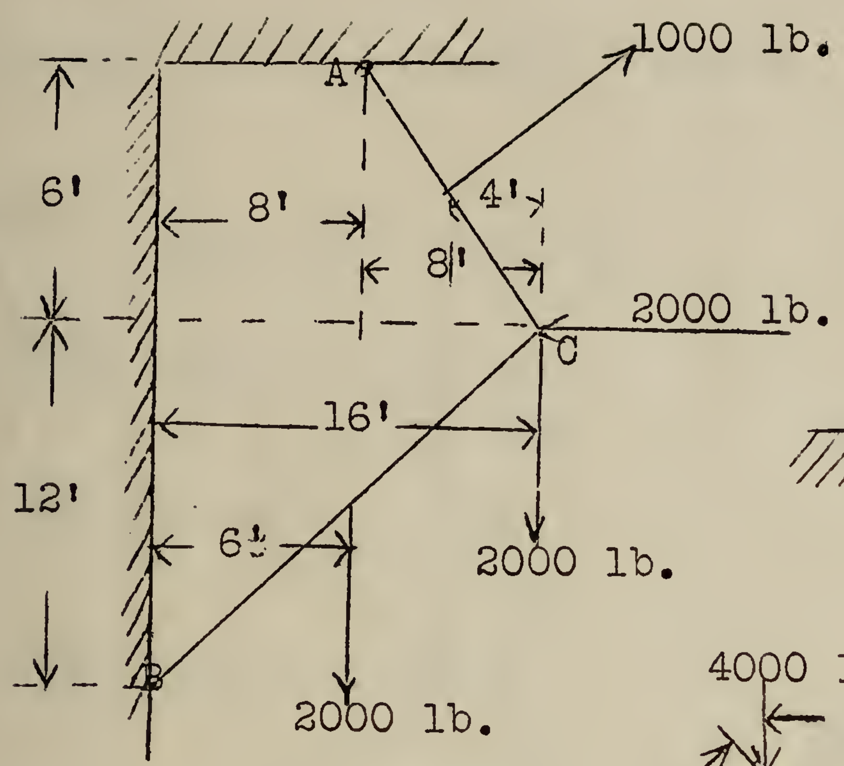
For generator take,

For A.C. Motor take,

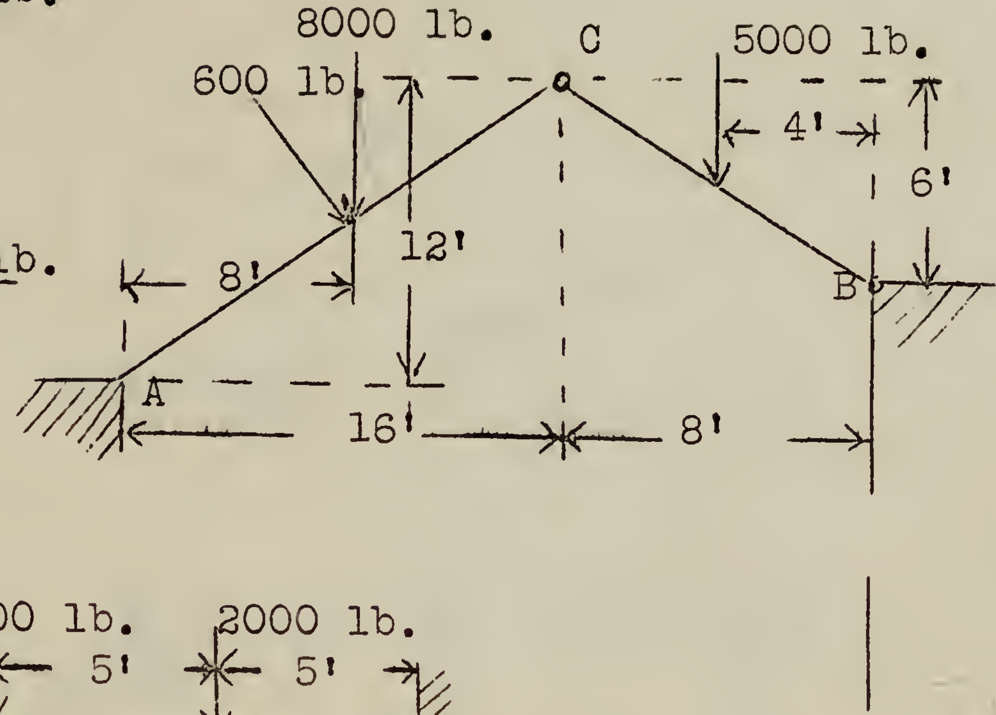
For fly wheel take,

Omit

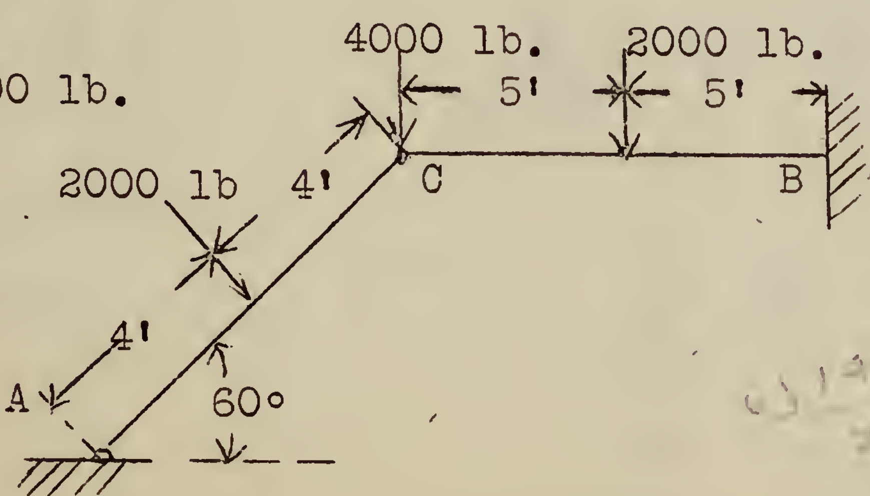
23.



24.



25.



26.

Omit

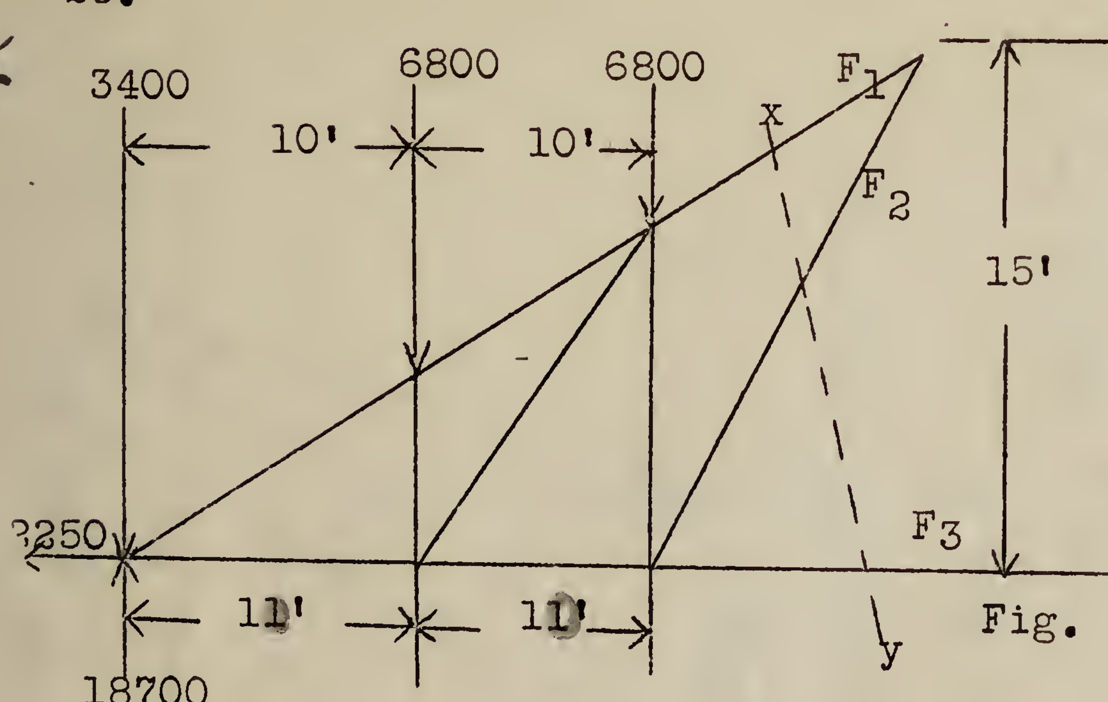
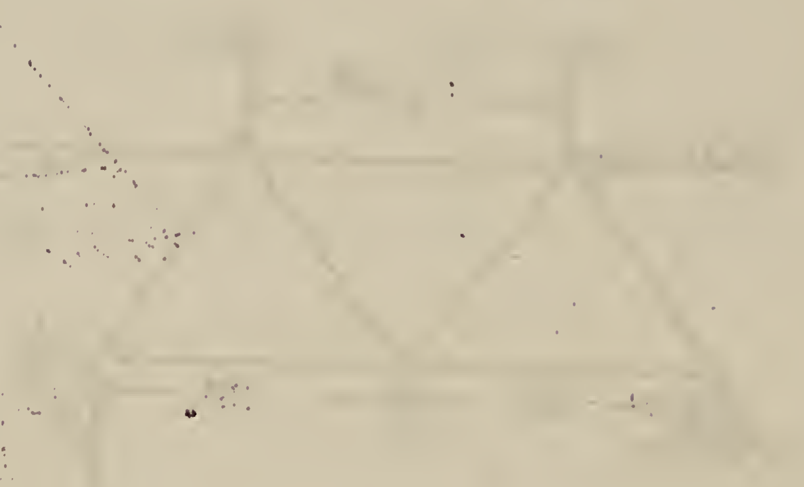
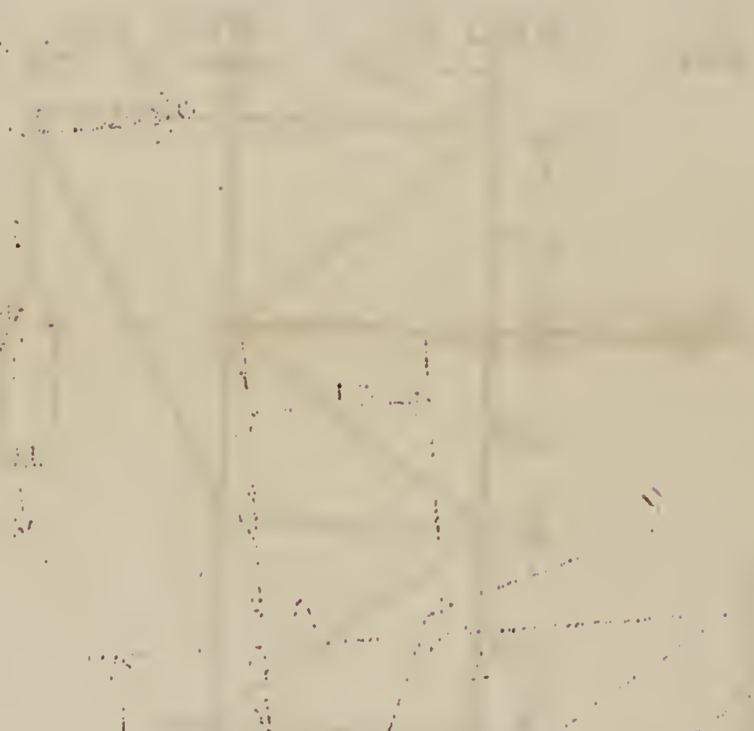
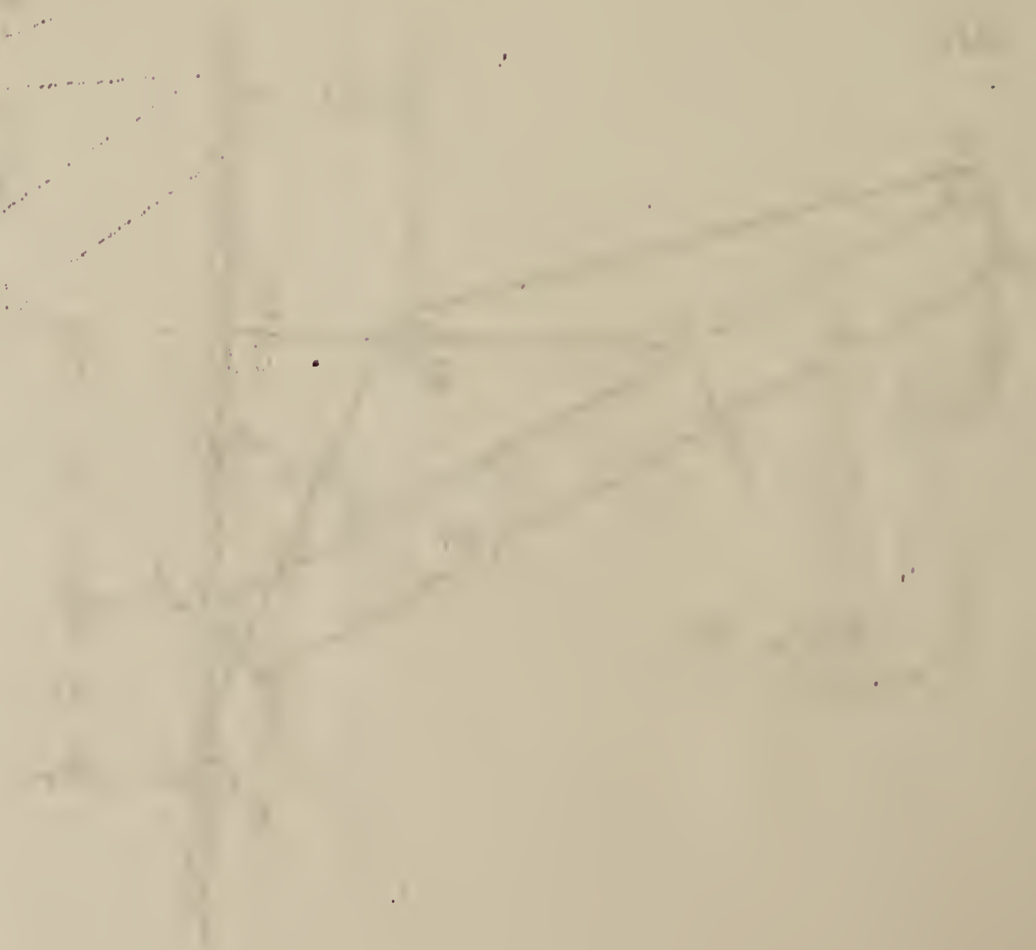


Fig. 26.

Find the stresses F_1, F_2, F_3 in the members cut by the section xy through the frame shown (Fig. 26)







Curves.

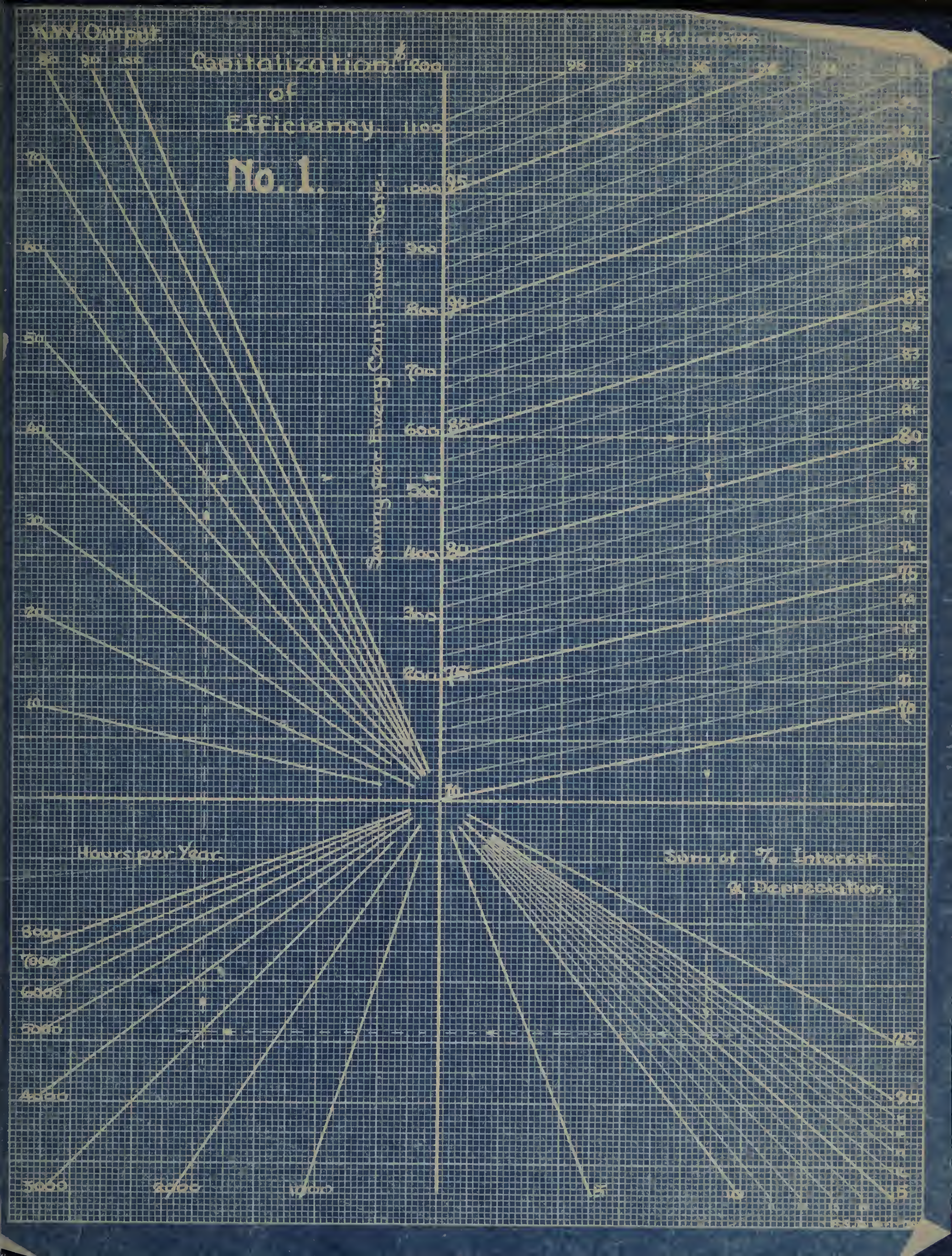
1.5 , 20, 100 350

$7 = 100^{\circ}$ 212 - 400

Tabulate

1. pres. or temp
2. heat of liquid
3. Sp. Vol.
4. total heat
5. E. of vaporiza
6. Entropy of L.
7. Heat of vaporiza
8. total Int. E.

Entropy, total

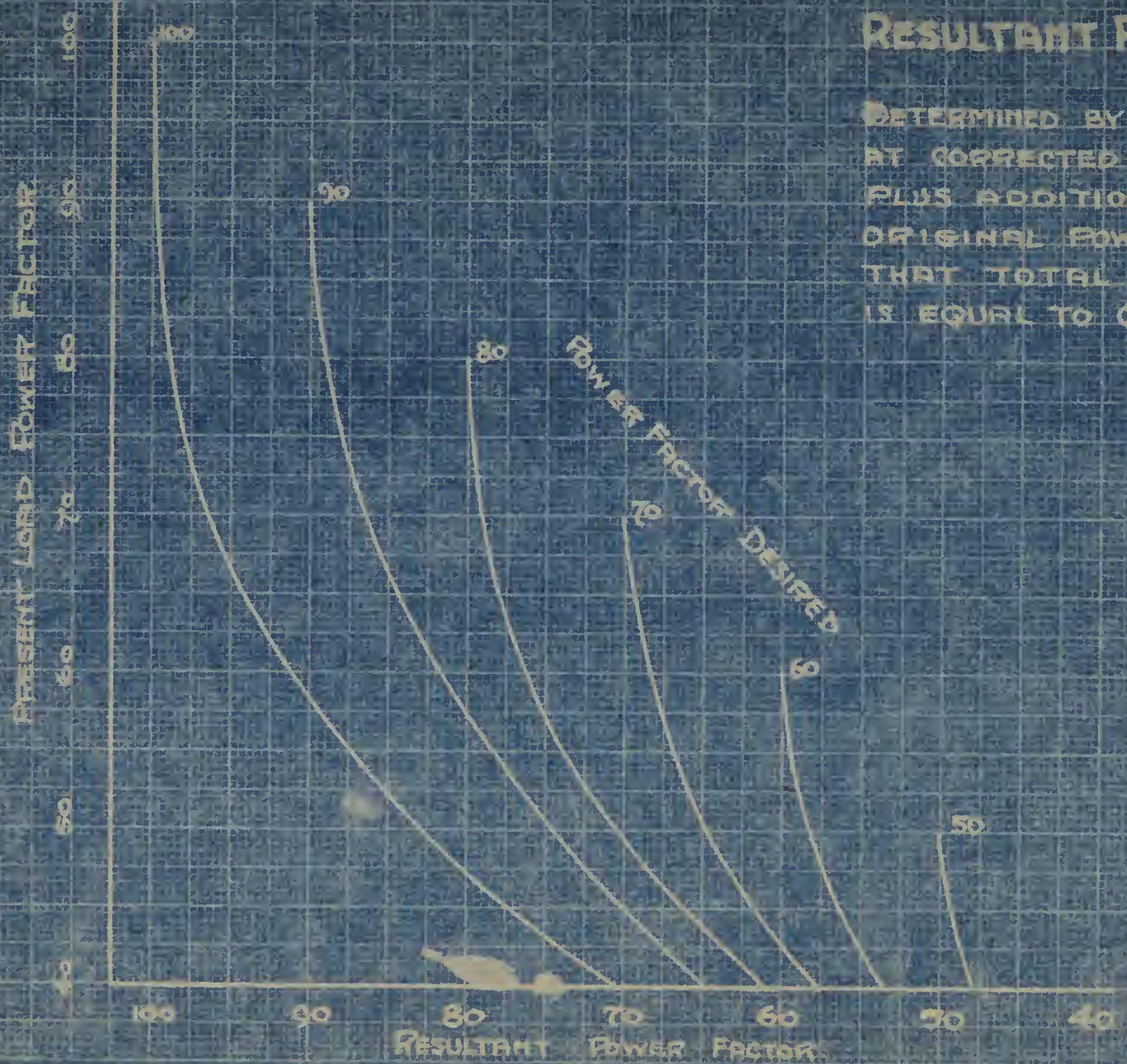


K.W. Output
Capitalization of Efficiency
No. 1.
Efficiencies
Saving Per Every Cent Power Rate
Hours per Year
Sum of % Interest & Depreciation.

No. 2.

Resultant Power Factor

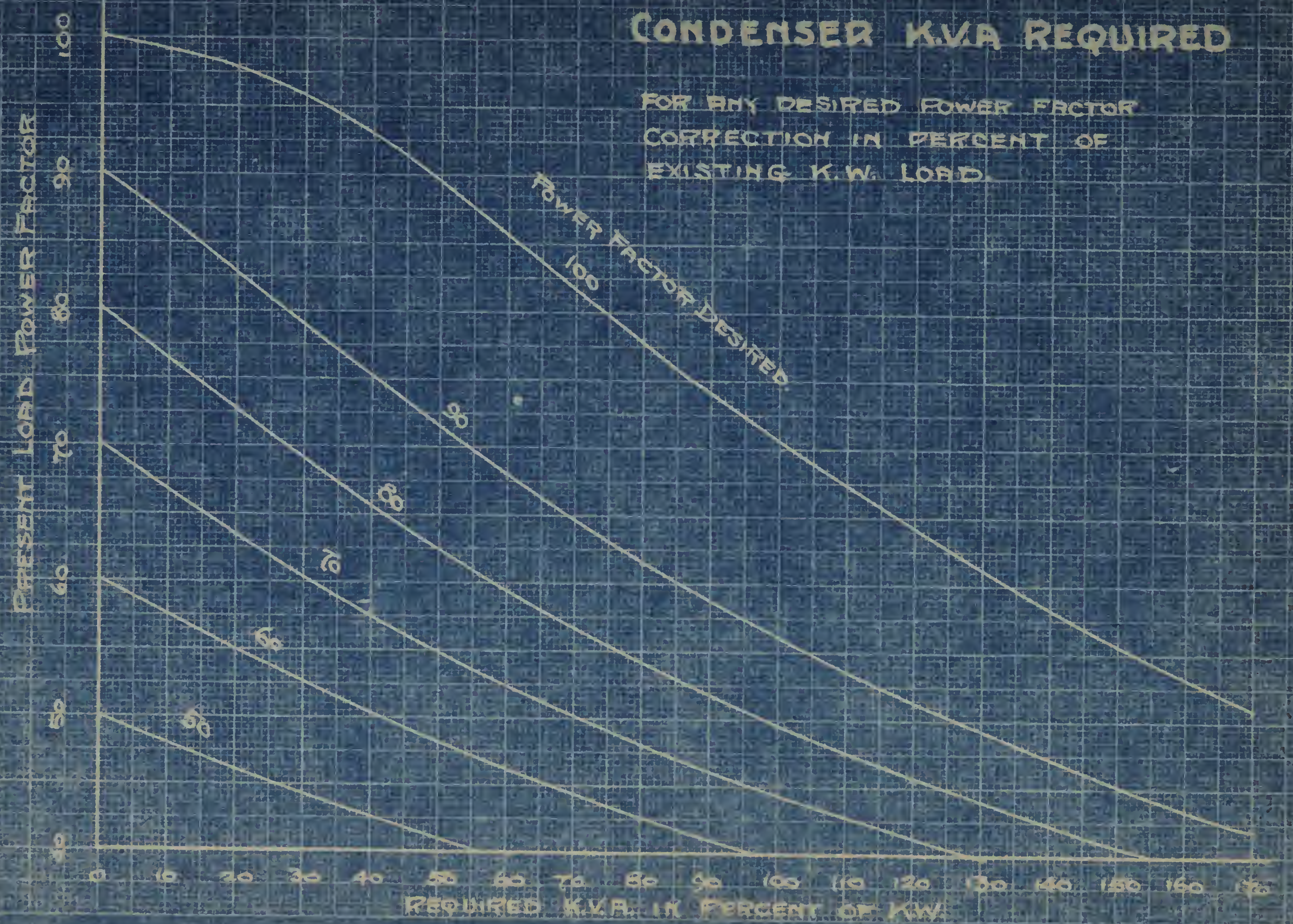
Determined by original load at corrected power factor plus additional load at original power factor so that total K.V.A. of circuit is equal to original K.V.A.

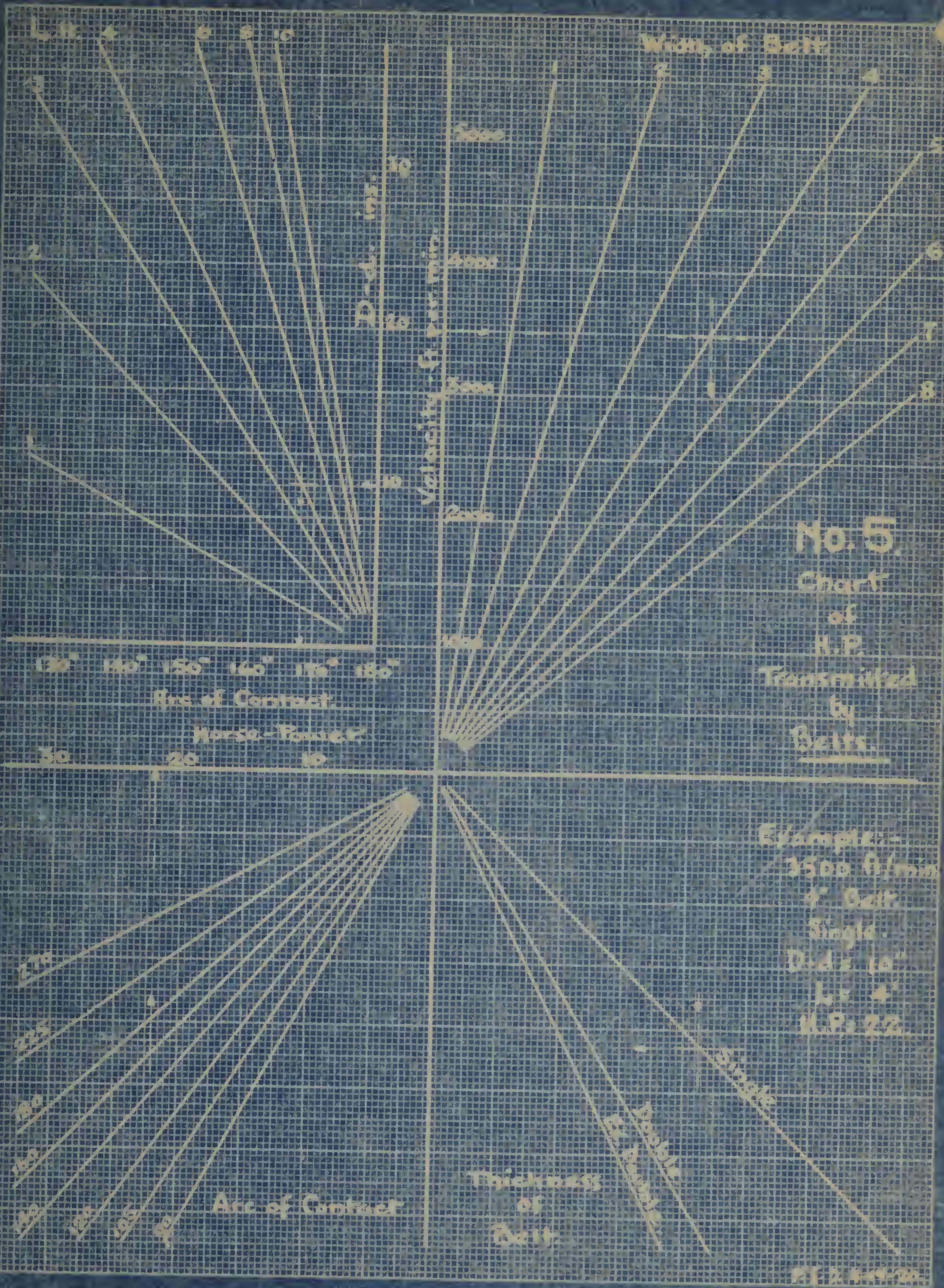


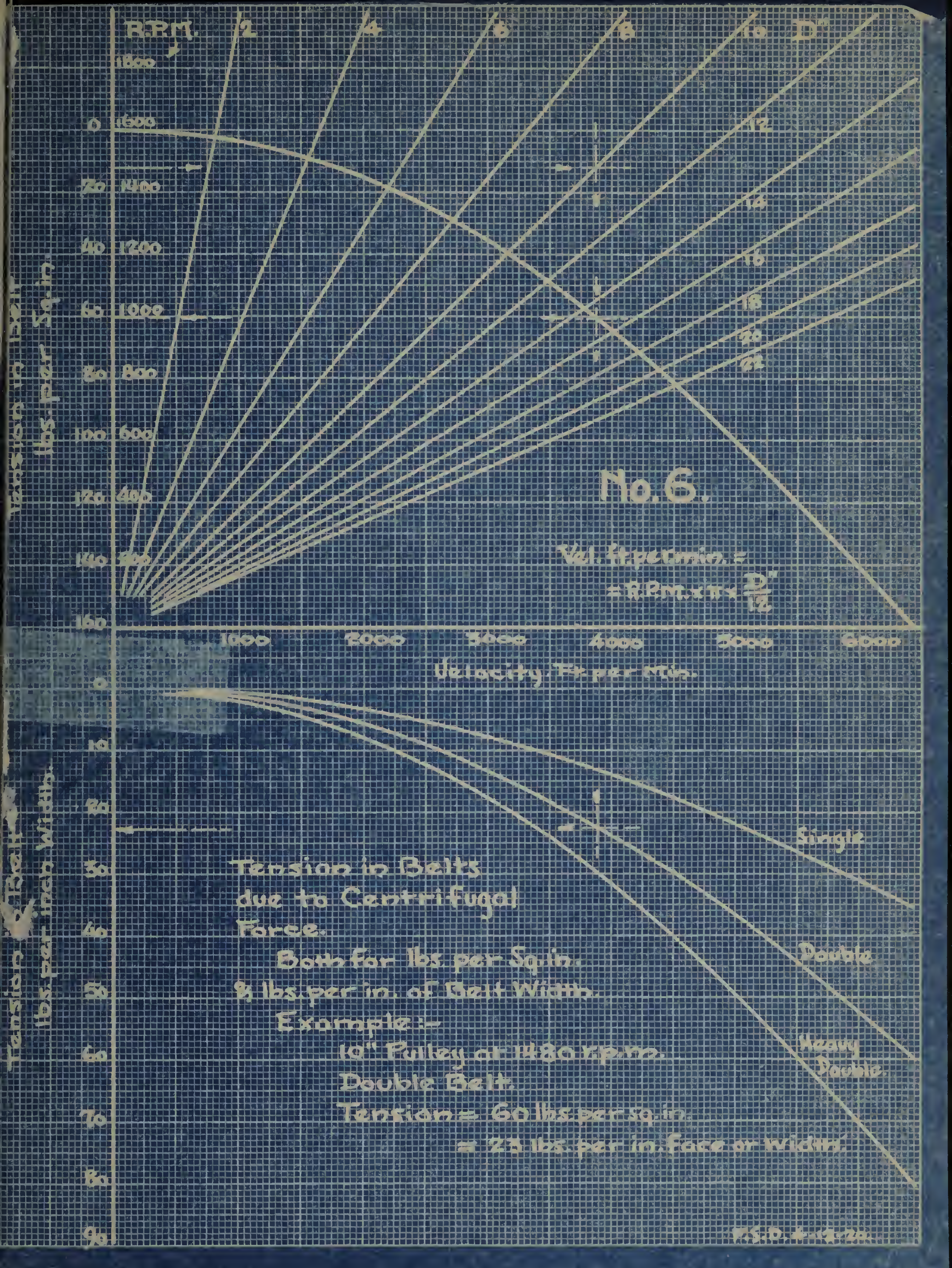
No. 3.

CONDENSER K.V.A. REQUIRED

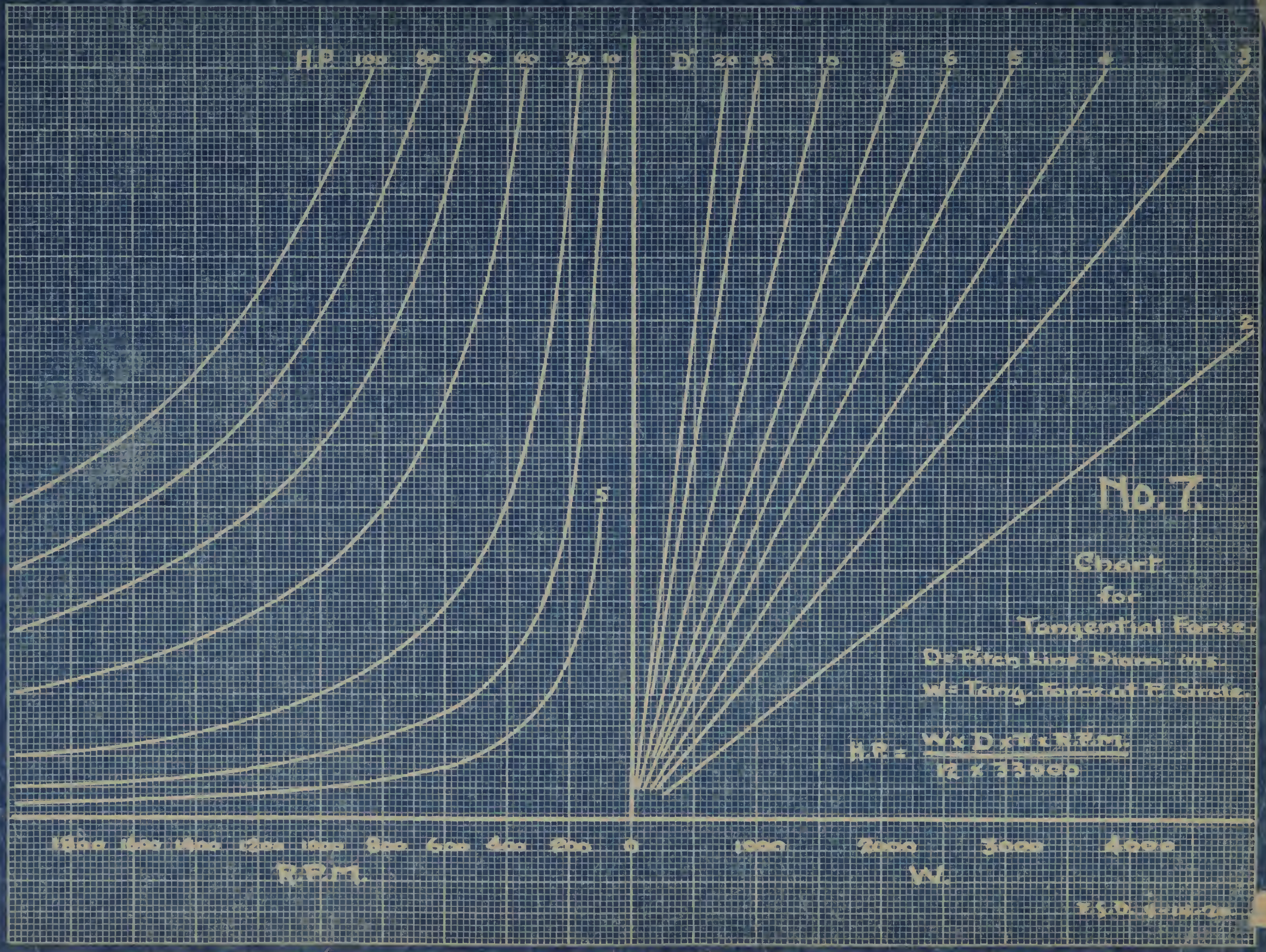
FOR ANY DESIRED POWER FACTOR CORRECTION IN PERCENT OF EXISTING K.W. LOAD.




No. 5.
Chart
of
H.P.
Transmitted
by
Belts.
Example:-
3500 ft/min
4" Belt
Single
D.d.= 14"
L= 4'
H.P. 22
Width of Belt
Velocity - ft. per min.
Arc of Contact
Horse-Power
30
20
10
Single
Double
Ex. Double
Thickness of Belt
Arc of Contact



R.P.M.
2
4
6
8
10
D"
12
14
16
18
20
22
1800
1600
1400
1200
1000
800
600
400
200
0
20
40
60
80
100
120
140
160
Tension in Belt lbs per Sq. in.
No. 6.
Vel. ft. per min. =
= R.P.M. x π x D"/12
1000
2000
3000
4000
5000
6000
Velocity Ft. per Min.
0
10
20
30
40
50
60
70
80
90
Tension in Belt lbs per inch Width.
Single
Double
Heavy Double.
Tension in Belts
due to Centrifugal
Force.
Both for lbs. per Sq. in.
& lbs. per in. of Belt Width.
Example:-
10" Pulley at 1480 r.p.m.
Double Belt.
Tension = 60 lbs per sq. in.
= 23 lbs. per in. Face or Width.
F.S.D. 4-12-20.

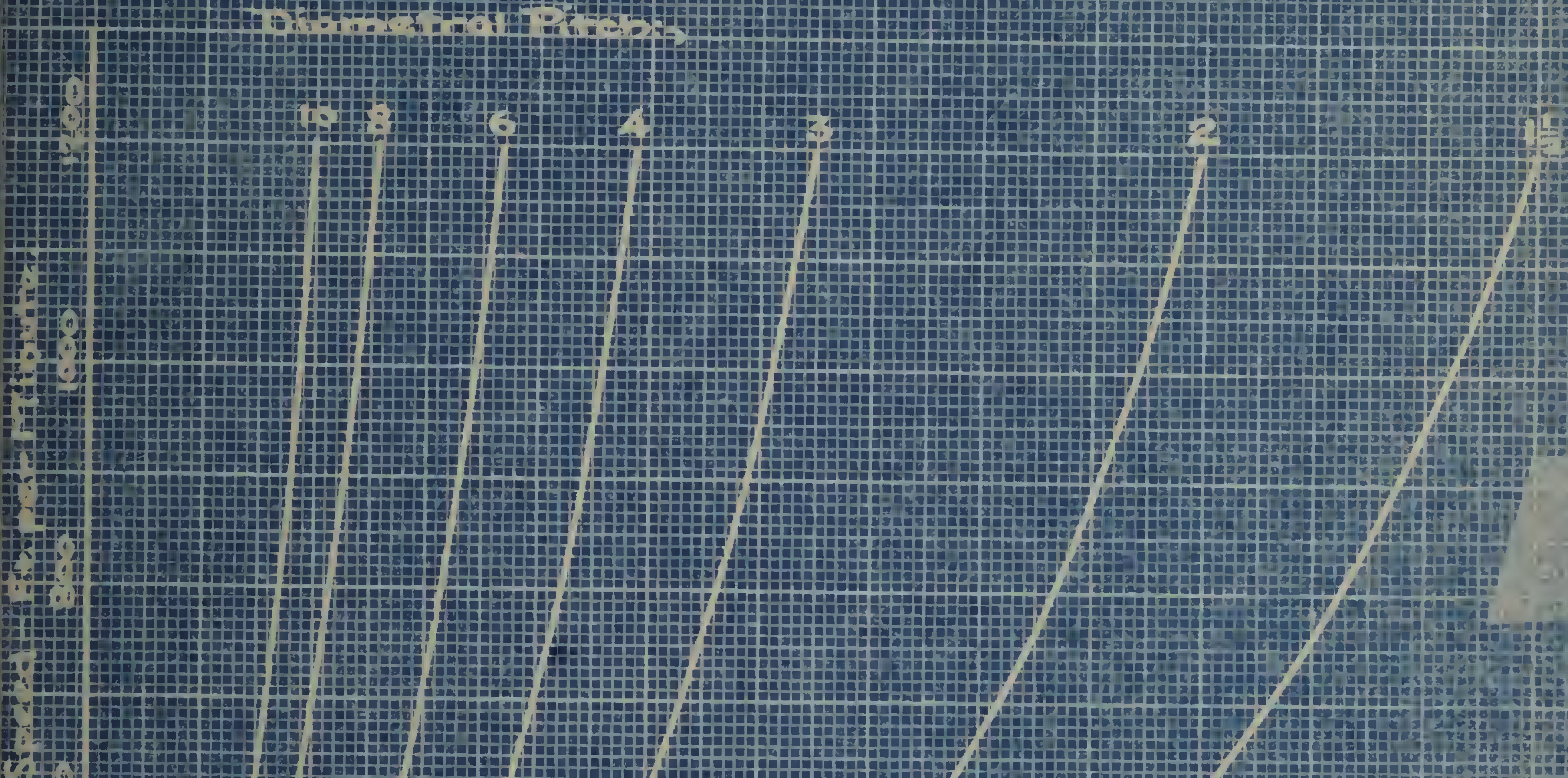


THE H. COLE CO. COLUMBUS, OHIO

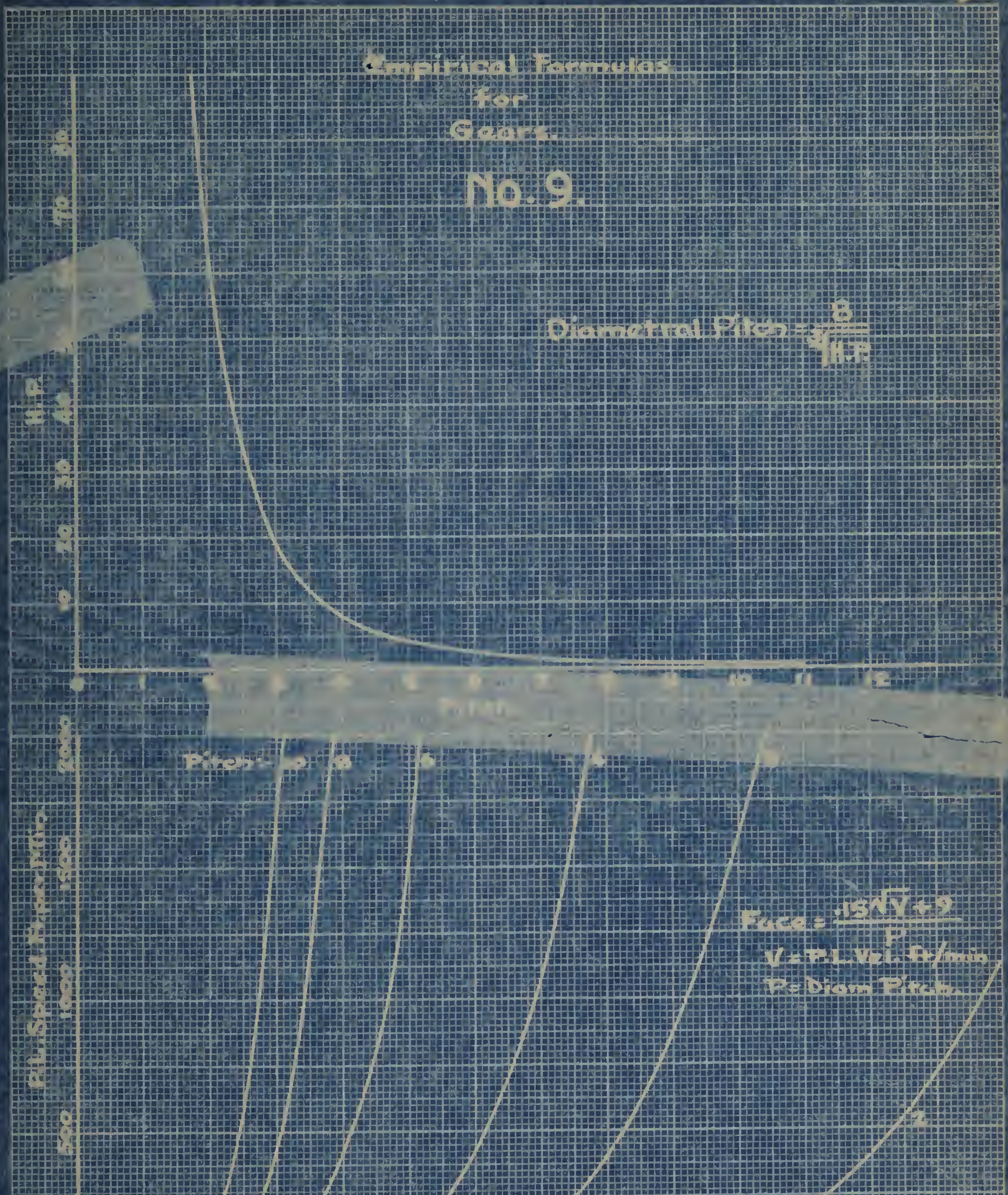
Average Horse Power that can be transmitted by Spur Gears

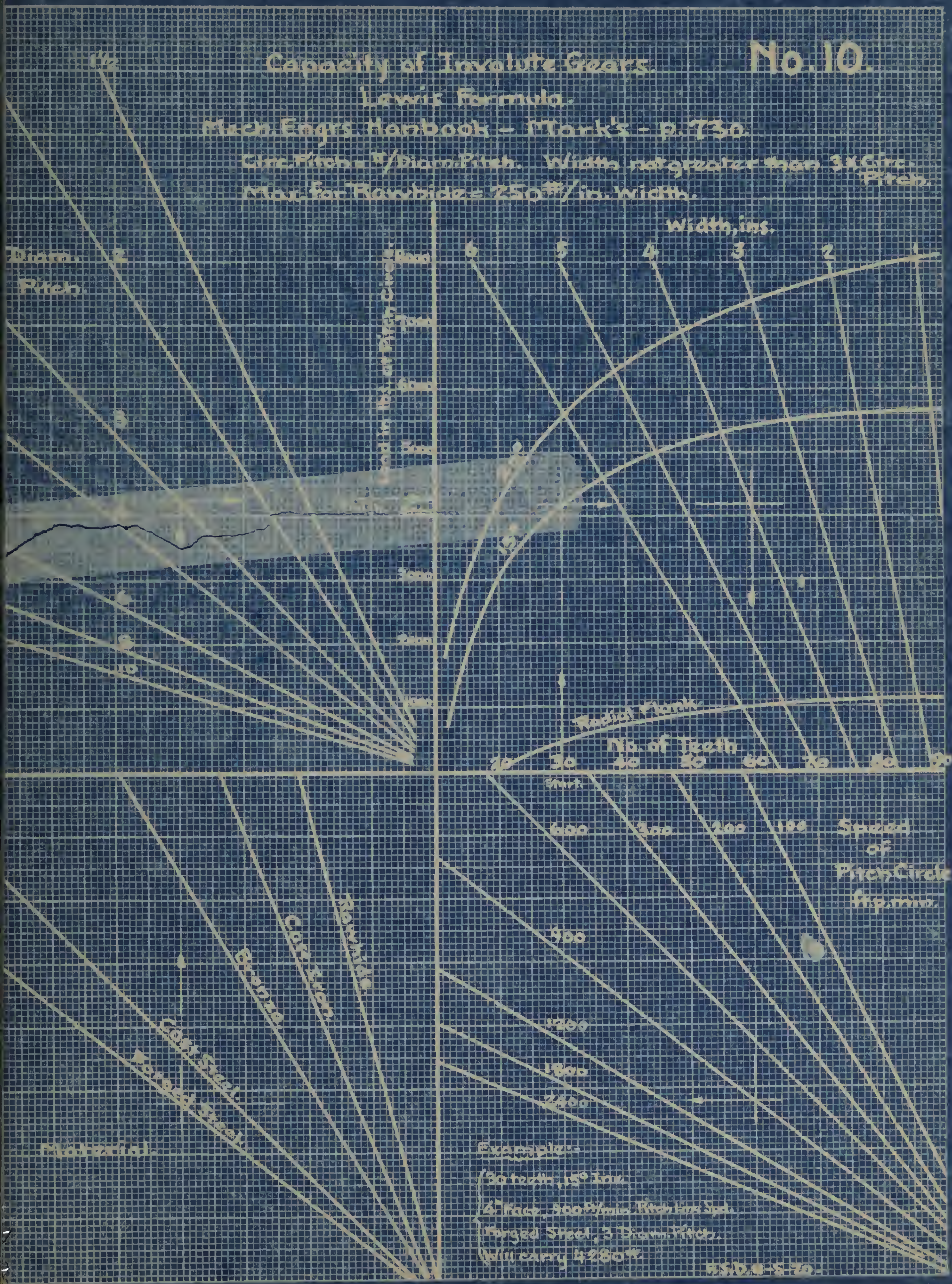
from data, p. 10. Sec. 23, Std. Handbook for Elec. Engrs.

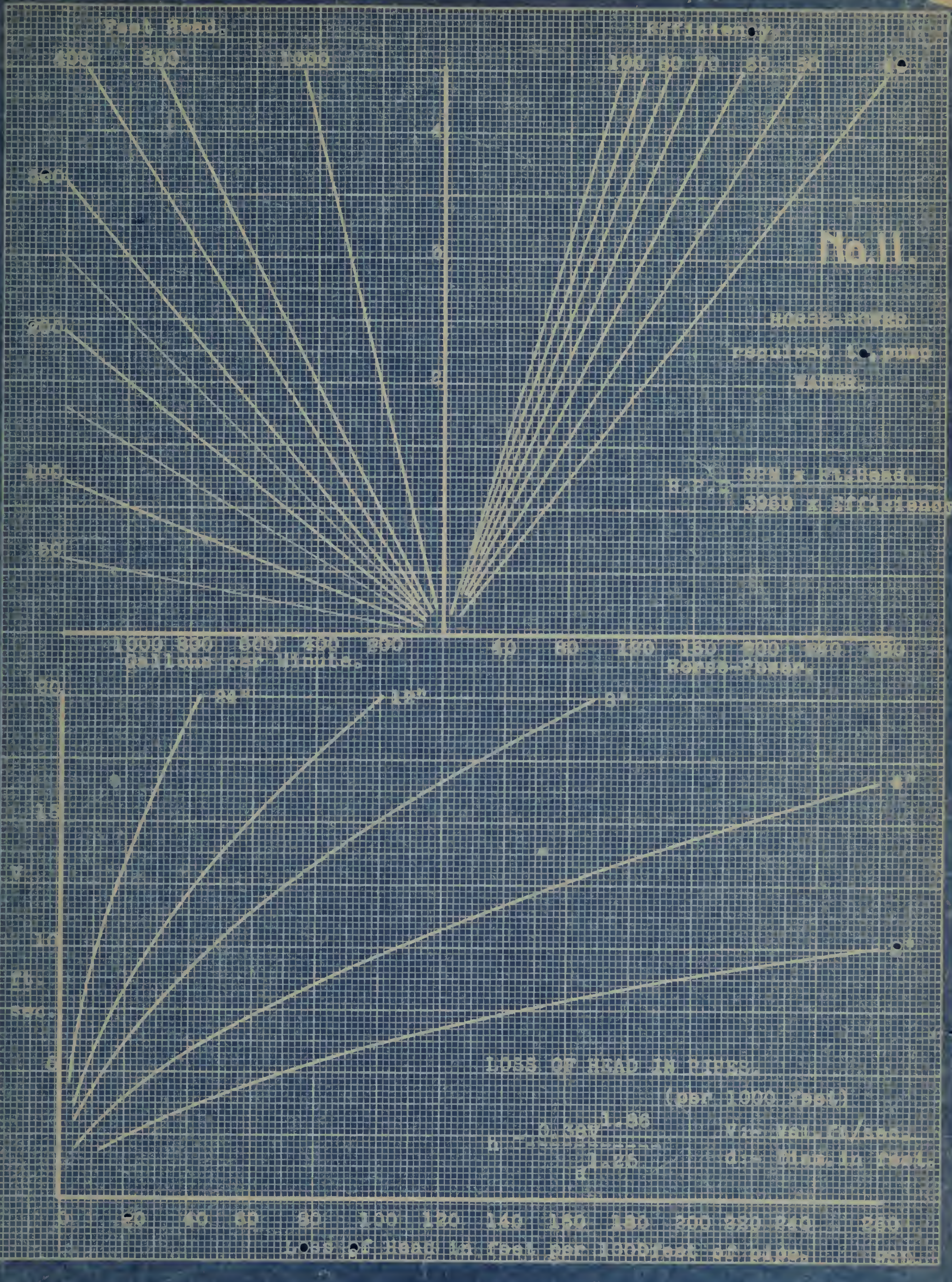
Values of H.P. for one inch face.

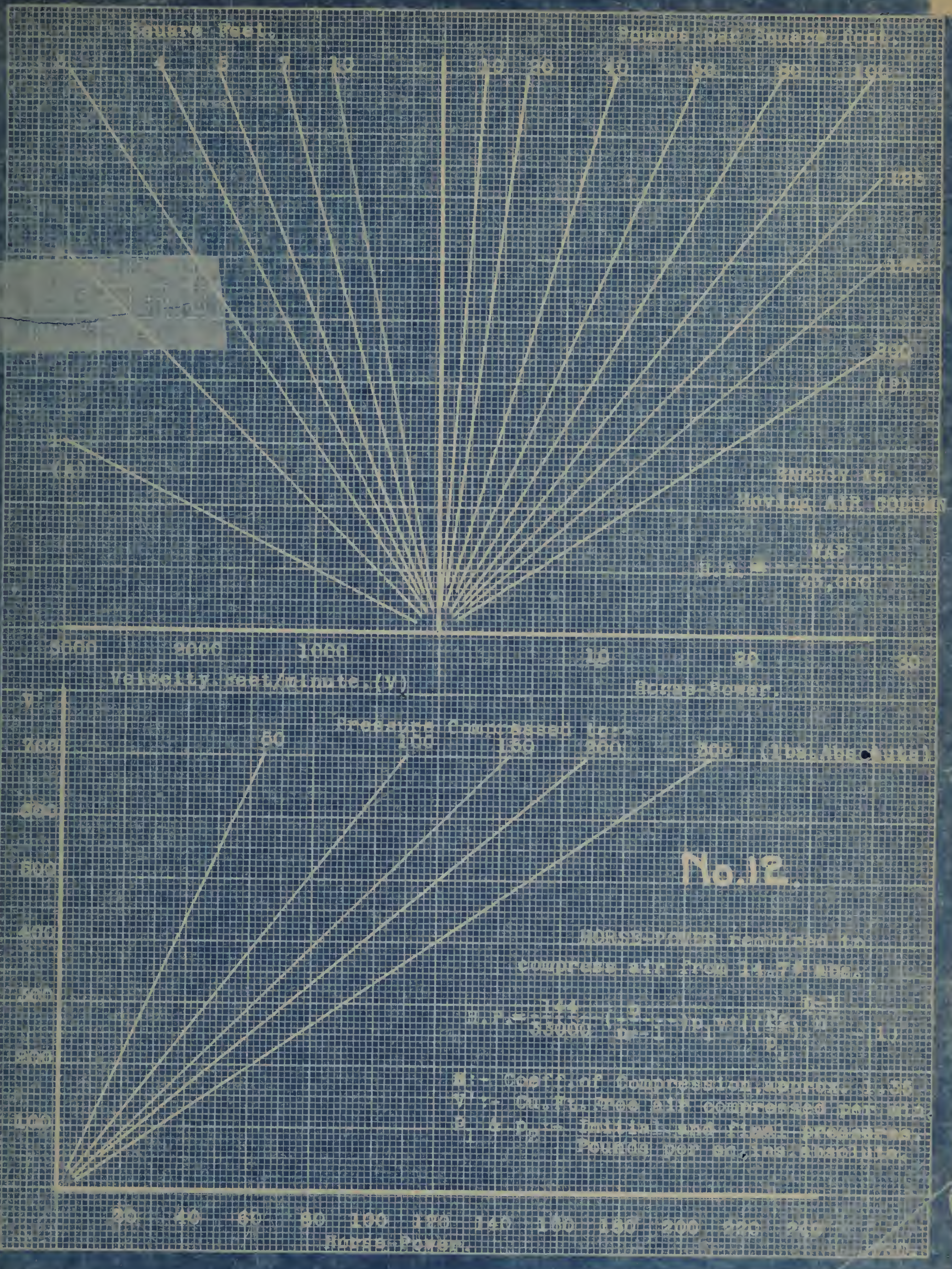


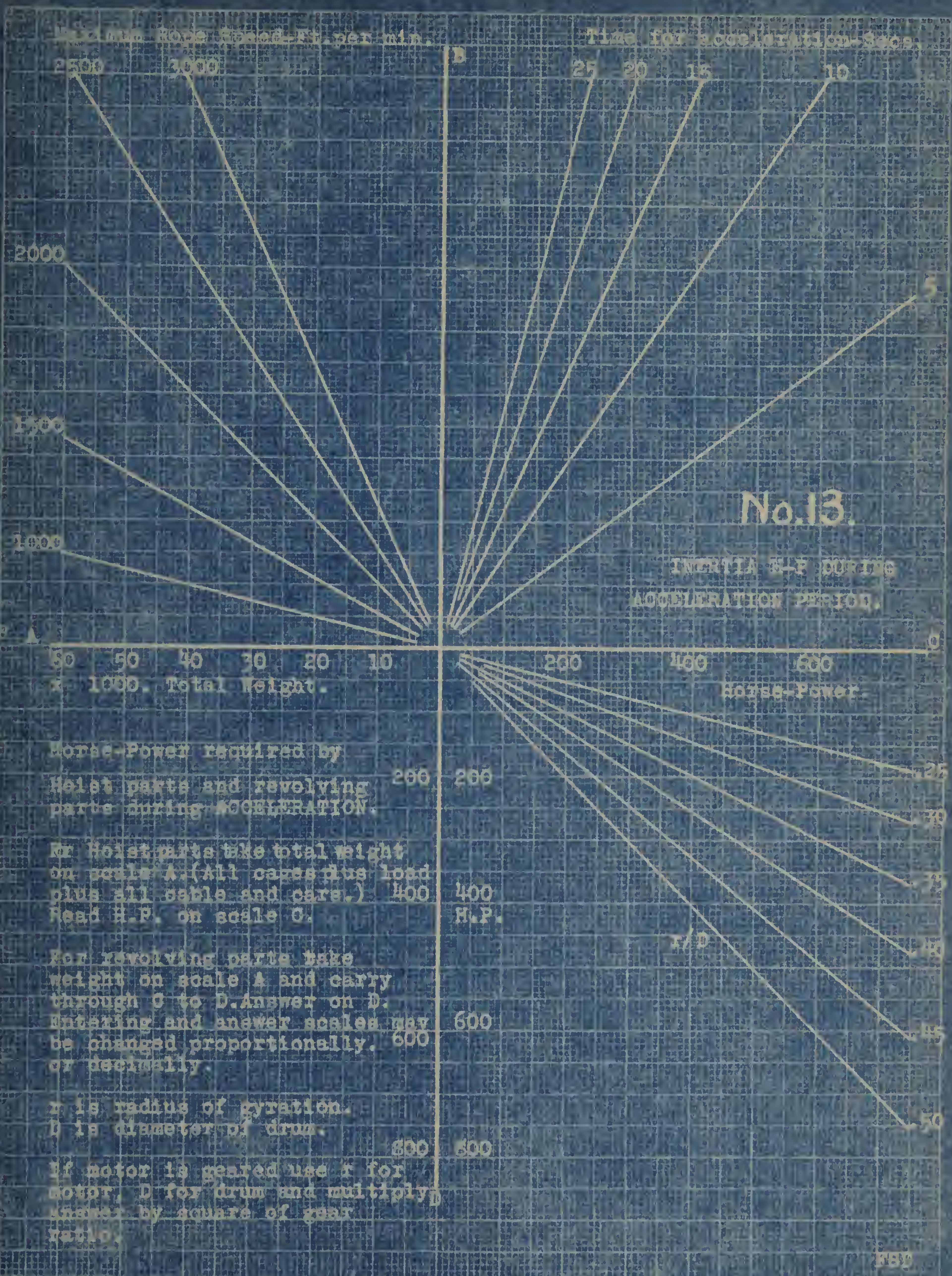
No. 8.


Empirical Formulas
for
Gears.
No. 9.
H.P.
Diametral Pitch = $\frac{8}{\sqrt[3]{H.P.}}$
Pitch
Face = $\frac{.15\sqrt{V}+9}{P}$
V = P.L. Vel. ft/min
P = Diam. Pitch.
P.L. Speed Ft. per Min.
Face-Inches
E.S.D.

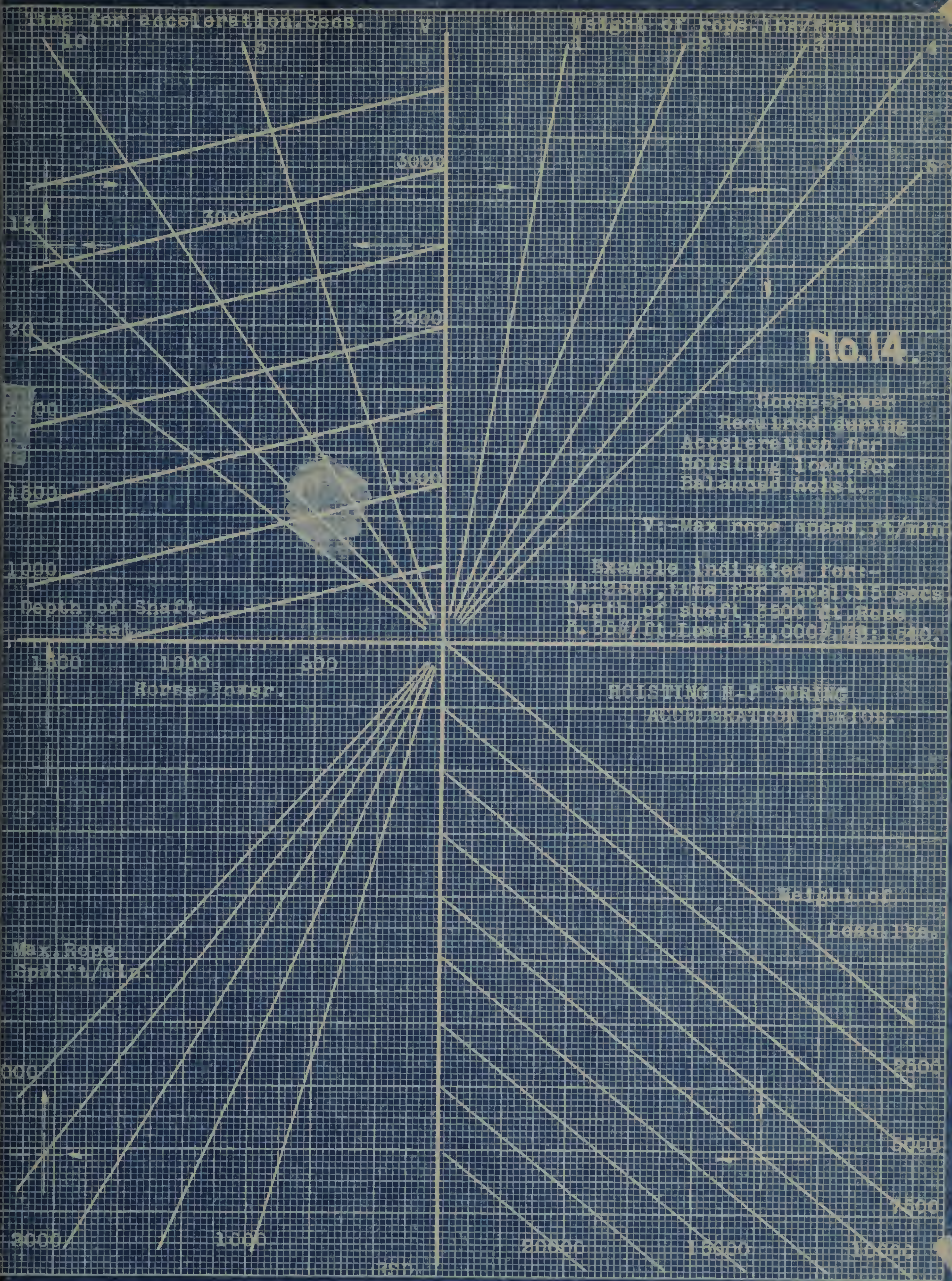

Capacity of Involute Gears.
No. 10.
Lewis Formula.
Mech. Engrs. Handbook - Mark's - p. 730.
Circ. Pitch = π/Diam. Pitch. Width not greater than 3 x Circ. Pitch.
Max. for Rawhide = 250#/in. Width.
Width, ins.
6
5
4
3
2
1
Diam. Pitch.
Radial Flank
No. of Teeth
20
30
40
50
60
70
80
90
Start
600
300
200
100
Speed of Pitch Circle ft. p. min.
900
1200
1800
2400
Rawhide
Cast Iron
Bronze
Cast Steel
Forged Steel
Material
Example:
30 teeth, 15° Inv.
4" Face, 300 ft/min. Pitch Line Spd.
Forged Steel, 3 Diam. Pitch.
Will carry 4280#


Feet Head.
400
500
1000
Efficiency.
100 90 70 60 50
No.11.
HORSE-POWER
required to pump
WATER.
3960 x Efficiency.
1000 800 600 400 200
Gallons per Minute.
40 80 120 160 200 240 280
Horse-Power.
20
15
10
5
24"
18"
9"
LOSS OF HEAD IN PIPES.
(per 1000 feet)
V = Vel. ft/sec.
d = Diam. in feet.
0 20 40 60 80 100 120 140 160 180 200 220 240 260
Loss of Head in feet per 1000 feet of pipe.

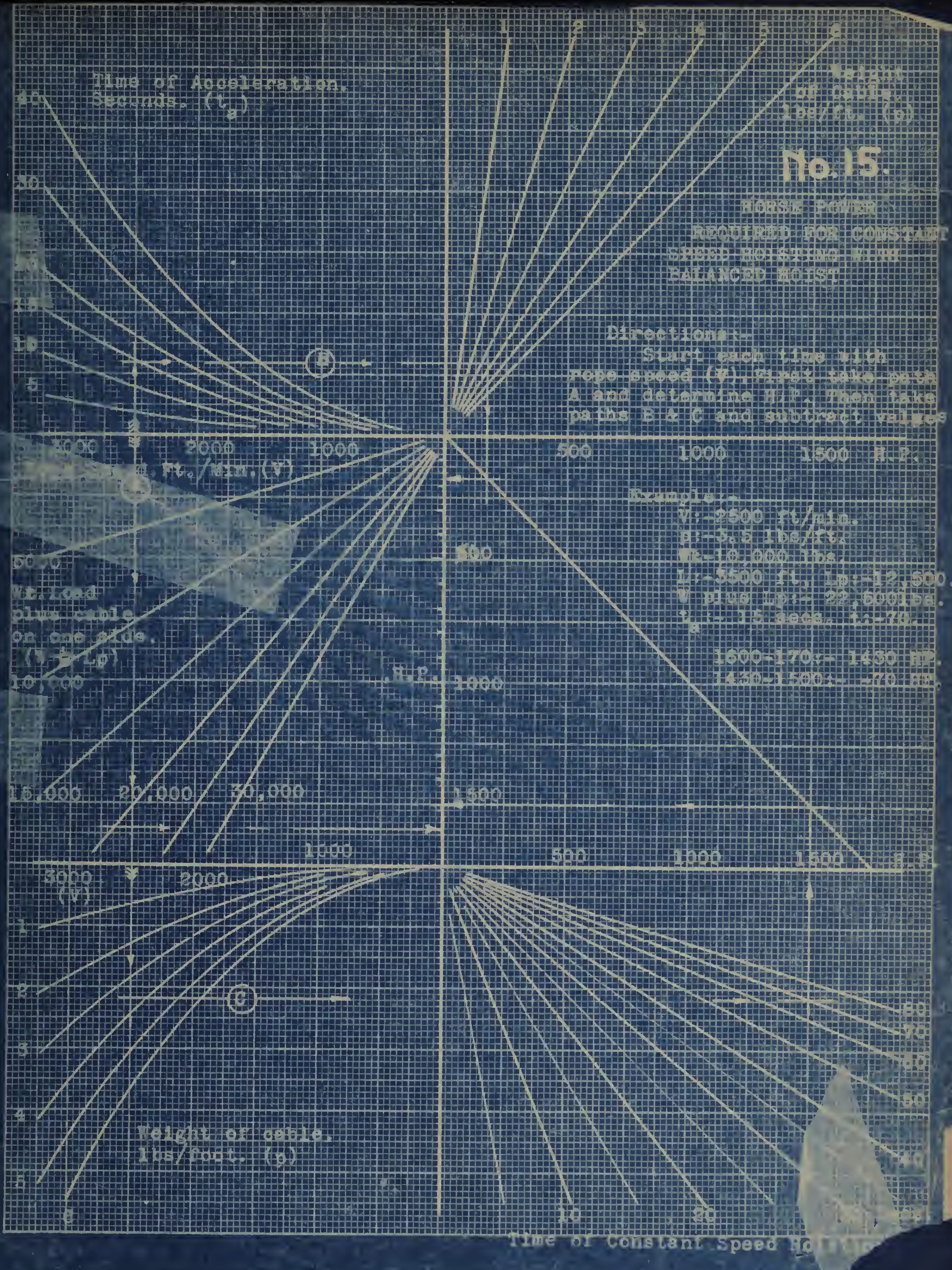

Square Feet.
Pounds per Square Inch.
ENERGY in Moving AIR COLUMN
3000
2000
1000
10
20
30
Velocity Feet/minute. (v)
Horse-Power.
Pressure Compressed Air
50
100
150
200
300
No.12.
HORSE-POWER required to compress air from 14.7# Abs.
Pounds per sq. ins absolute.
20
40
60
80
100
120
140
160
180
200
220
240
Horse-Power.



Rope Speed-Ft. per min.
Time for acceleration-Secs.
2500
3000
D
25
20
15
10
2000
5
1500
No.13.
1000
INERTIA H-P DURING
ACCELERATION PERIOD.
A
C
60
50
40
30
20
10
200
400
600
x 1000. Total Weight.
Horse-Power
Horse-Power required by
Hoist parts and revolving
parts during ACCELERATION.
For Hoist parts take total weight
on scale A.(All cases plus load
plus all cable and cars.)
Read H.P. on scale C.
200
200
400
400
H.P.
r/D
For revolving parts take
weight on scale A and carry
through C to D.Answer on D.
Entering and answer scales may
be changed proportionally,
or decimally.
600
600
r is radius of gyration.
D is diameter of drum.
800
800
If motor is geared use r for
motor, D for drum and multiply
answer by square of gear
ratio.
D



Time for acceleration.Secs.
V
Weight of Rope.lbs/foot.
No.14.
Horse-Power
Required during
Acceleration for
Hoisting load.For
Balanced hoist.
V:-Max rope speed.ft/min
Example indicated for:-
Depth of Shaft.
feet.
Horse-Power.
HOISTING H.P DURING
ACCELERATION PERIOD.
Weight of
Load.lbs.
Max.Rope
Spd.ft/min.


Time of Acceleration.
Seconds. (t_a)
Weight
of Cable.
lbs/ft. (p)
No. 15.
HORSE POWER
REQUIRED FOR CONSTANT
SPEED HOISTING WITH
BALANCED HOIST
Directions:-
Start each time with
rope speed (V). First take path
A and determine H.P. Then take
paths B & C and subtract values.
Ft./Min. (V)
3000
2000
1000
500
1000
1500 H.P.
Example:-
V:-2500 ft/min.
p:-5.5 lbs/ft.
W:-10,000 lbs.
L:-3500 ft. Lp:-12,500.
W plus Lp:- 22,500lbs.
t_a:- 15 secs. t:-70.
1600-170:- 1430 HP.
1430-1500:- -70 HP.
Wt. Load
plus cable
on one side.
(W + Lp)
10,000
15,000
20,000
30,000
H.P.
500
1000
1500
(V)
Weight of cable.
lbs/foot. (p)
10
20
Time of Constant Speed Hoisting